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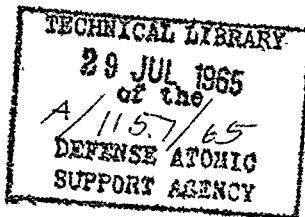
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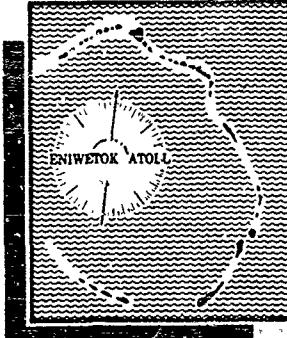
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*Operation*  
**IVY**  
**PACIFIC PROVING GROUNDS**



November 1952

TECHNICAL PHOTOGRAPHY



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No. 193 of 200 copies, Series A

Report to the Scientific Director

TECHNICAL PHOTOGRAPHY [47]

By

Staff of

Edgerion, Germeshausen & Grier, Inc.

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### ENIWETOK ATOLL

## ABSTRACT

~~Edgerton Germeshausen & Grier, Inc. (EG&G)~~ was commissioned to carry out the following photographic activities on Operation Ivy; were carried out.

- 1) Determine fireball yield from high-speed cameras and Rapatronics.
2. Record cloud-rise and -drift phenomena.
3. Determine luminous emittance of the fireball.
4. Determine time to the minimum by means of Bhangmeters.
5. Determine position of burst for King shot.
6. Record mortar and gun bursts for J-10.
7. Record water wave from Mike shot.
8. Record smoke rocket trails on King shot.
9. Record the television monitor screen on Mike shot from M-1 hr to zero time.
10. In addition, ~~EG&G~~ operated an experimental GMX-9 camera, an experimental Telescopic Rapatronic camera, and an image-converter camera.

Fireball yield was determined to be  $10,900 \pm 500$  KT for Mike shot and  $575 \pm 5$  KT for King shot.

The Mike cloud reached a maximum height of slightly over 100,000 ft in about 4 min, at which time the diameter had become about 100,000 ft. At the end of 1 hr the cloud had spread out over a range of 300,000 ft. The King cloud attained its maximum height of 65,000 ft in slightly over 4 min, while growing to a 40,000-ft diameter.

Bhangmeter records on Mike shot were not adequate to determine the time to the minimum. King Bhangmeters gave an average time to the minimum of 68 msec, which is scaled to a yield of  $440 \pm 90$  KT.

King position of burst with respect to the Coral Survey Station (N 100,000, E 100,000) was determined to be

N  $108,450 \pm 30$ , an error of 300' N  
E  $123,650 \pm 20$ , an error of 480' W  
Height,  $1480 \pm 20$  ft above sea level

This position corresponds to latitude N  $11^{\circ}33'44''$  and longitude E  $162^{\circ}21'09''$ .  
The disposition of the film prints is outlined in Appendix B.

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CHAPTER 1

**INTRODUCTION**

Various types of photostations were used in Operation Ivy. A 125-ft tower (Station 301), shown in Fig. 1.1, was located on Elmer. Figure 1.2 shows some of the cameras installed in the racks. A second photostation (Station 302) was set up on a concrete pier at the foot of this tower, with cameras enclosed in heavy lead boxes mounted on top of the pier. The lead boxes were employed as shielding against the possible heavy fall-out radiation. A third station on Elmer (Station 308) was located inside the control-room compound. Three other major photostations constructed similarly to Station 302 were built on top of existing timing stations on Janet (Station 303), Ursula (Station 306), and Yvonne (Station 307). In addition, an Eastman Cine Special camera was mounted on a special concrete column on Ursula (Station 305) to record water-wave motion on Mike shot. For King shot the coral station Oscar (Station 304) was activated with two Galileo phototheodolites to record position of burst. Figure 1.3 indicates the positions of the several ground stations.

Supplementary yield cameras were operated on Mike shot from the USS Estes, primarily to provide a means of determining yield quickly should reentry to the atoll be delayed. Cloud-rise photography on Mike shot was documented from both the USS Curtiss and the USS Estes, as well as from two C-47 aircraft flying at varying distances from Ground Zero.

Because of the high levels of fall-out radiation that could be expected from Mike shot, all the ground-station cameras were shielded by lead boxes whose sides consisted of  $1\frac{1}{2}$  in. of lead sandwiched between  $\frac{1}{2}$  in. of steel plate. These boxes were made in two sizes, one for the larger cameras and the other for the smaller ones. Figure 1.4 illustrates a typical shielded-camera installation.

Timing signals were sent from the master timing station on Flora through cables either direct to the photostation or relayed through auxiliary timing stations. These signals, occurring at -15 min and -15, -2.5, -1.5, and -0.5 sec, closed DN-11 relays, which caused various of the camera electrical circuits to be closed, thereby making the cameras operate at the proper time. Block diagrams of the various photostations are presented in Appendix A. Further information on the timing and control systems of Ivy may be found in Report WT-609, Timing and Firing and Fiducial Markers.

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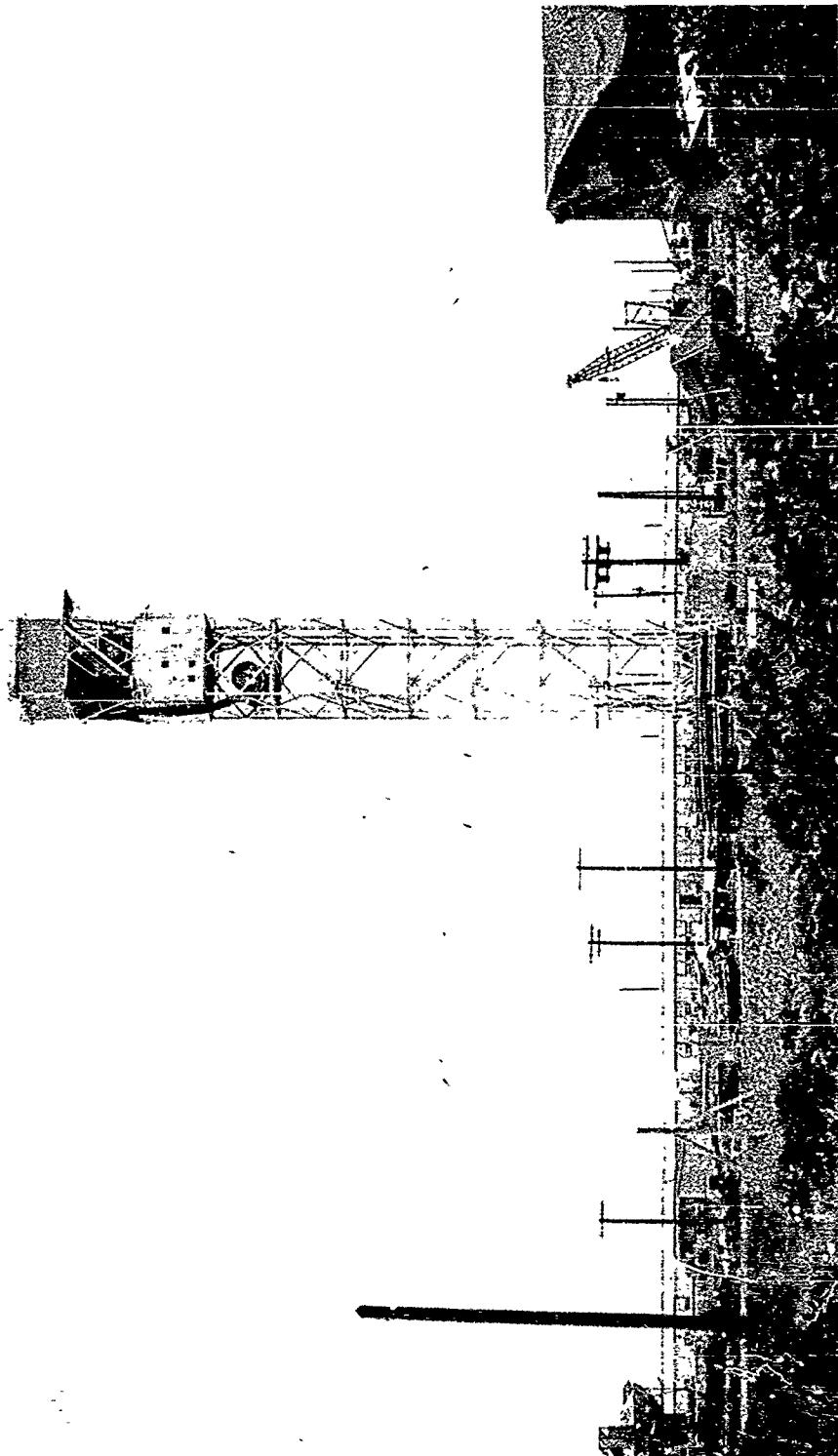


Fig. 1.1—Elmer phototower, St. 301.

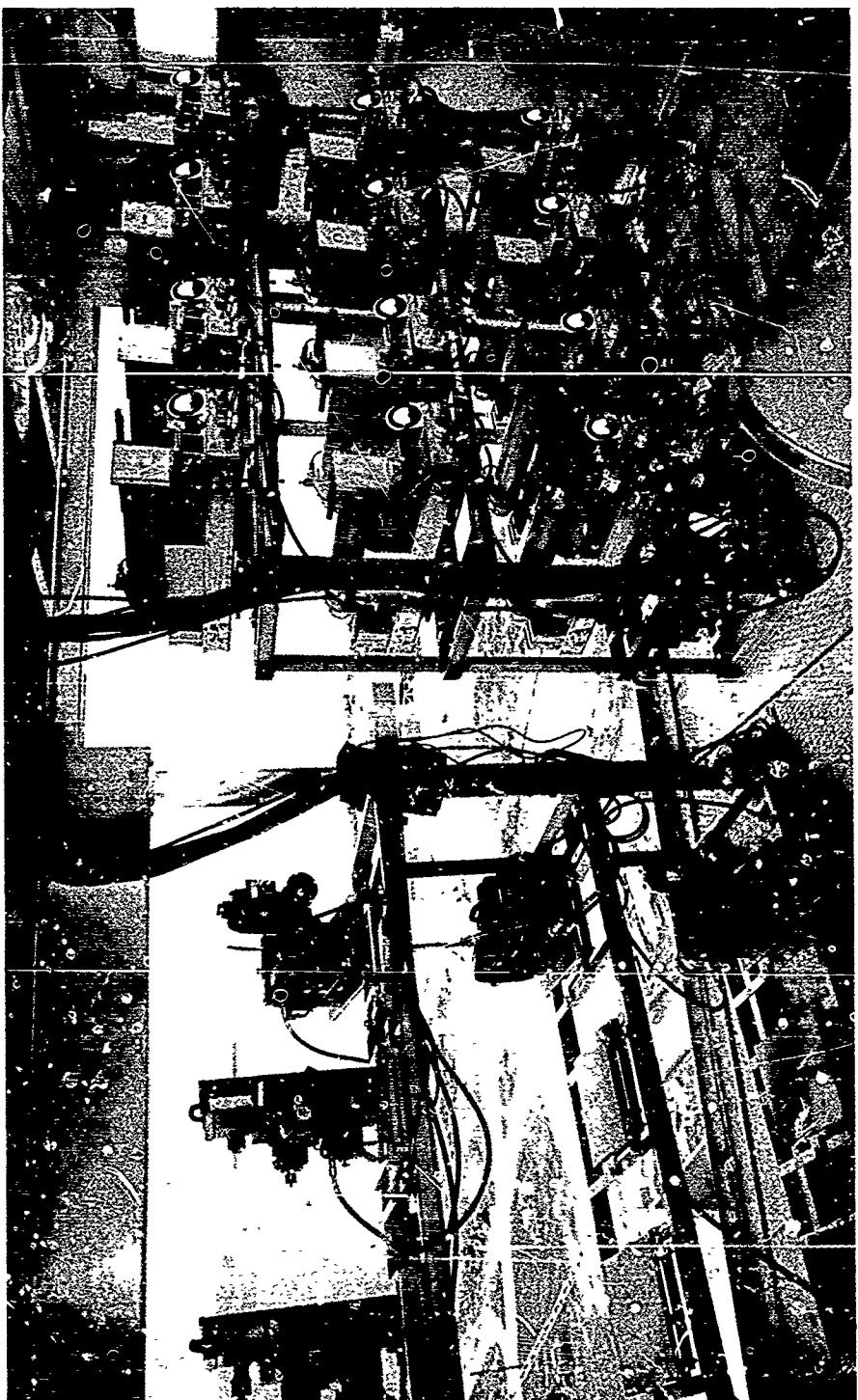
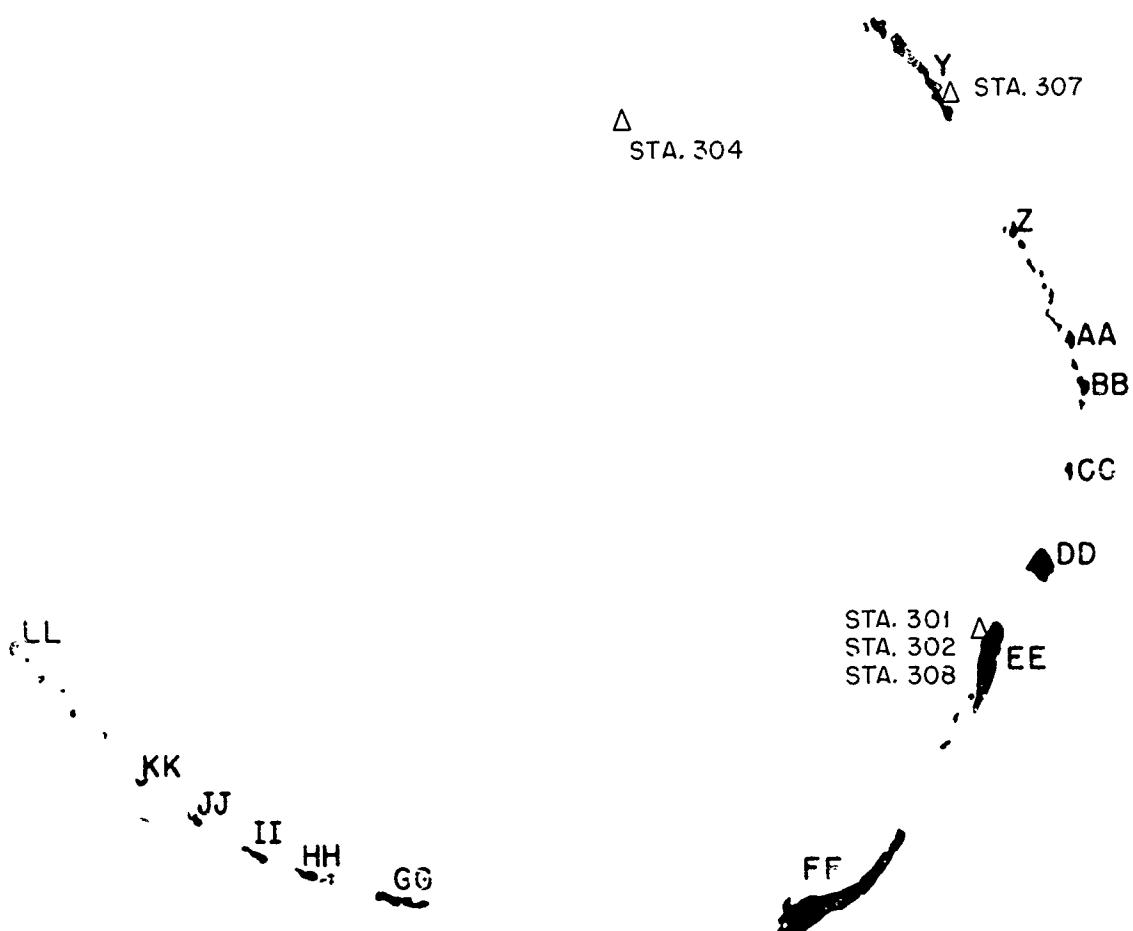
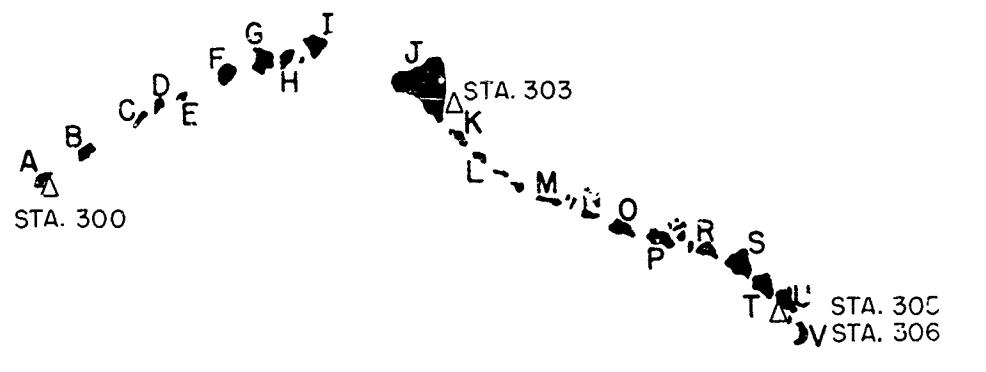


Fig. 1.2---Camera Installation, Station 301.



### ENIWETOK ATOLL

Fig. 1.3—Map of photostations.

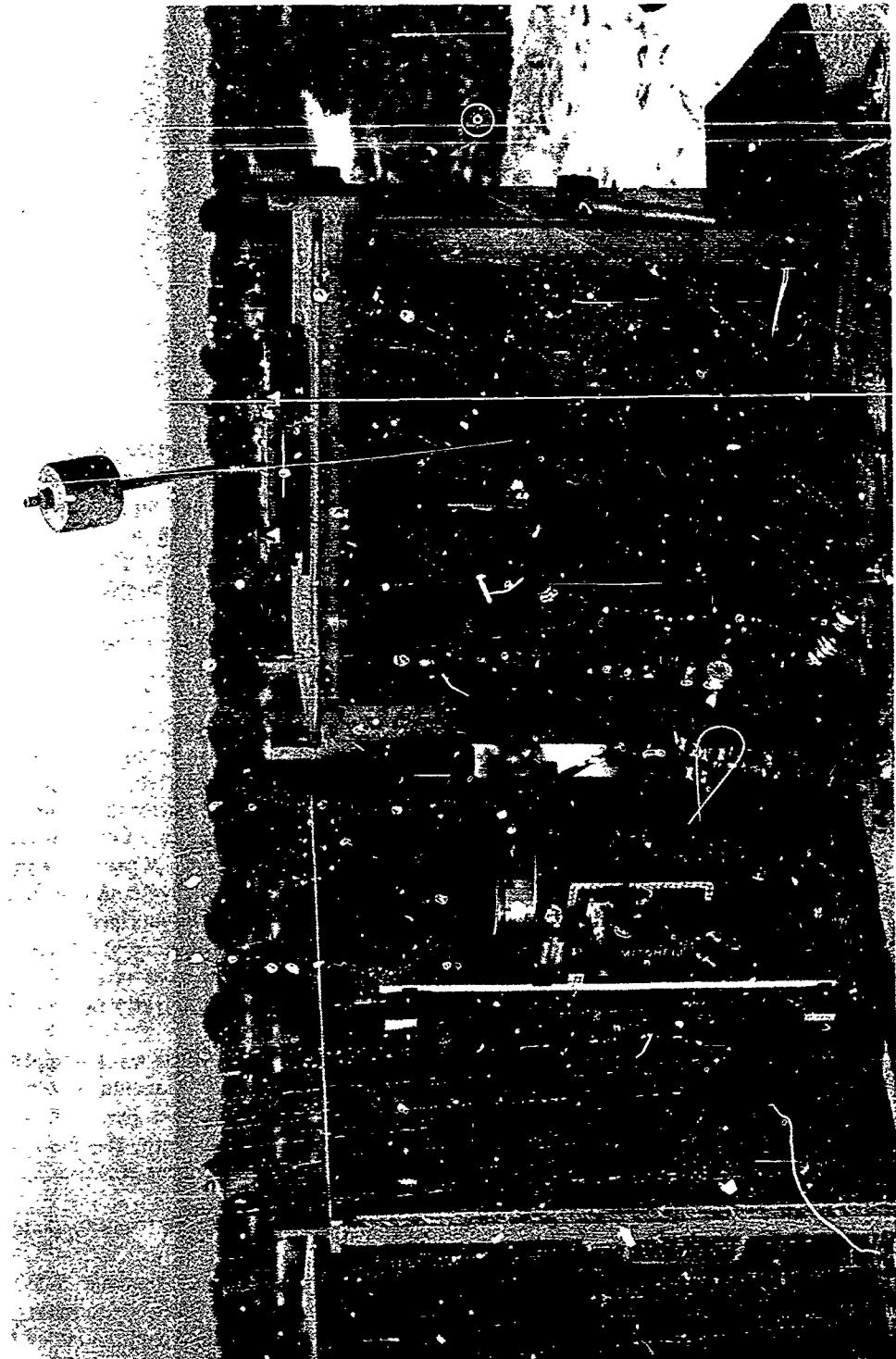


Fig. 1.4—Typical shielded-camera installation.

## CHAPTER 2

### FILM HANDLING

A fully equipped photo-processing trailer belonging to Edgerton, Germeshausen & Grier, Inc. (EG&G), was shipped to Eniwetok to take care of all black-and-white processing requirements. Films were stored in refrigerators on Elmer until needed. At least one complete camera dry run was made before each shot, and films used for this run were perforated, loaded, and processed just as for a live run. Film was taken out of the refrigerators, perforated with the appropriate EG&G identification number, exposed to a sensitometric strip and reticle, and readied for loading into cameras at least 24 hr before the scheduled shot time.

As soon as possible after the shot was fired, recovery parties returned to the photo-stations and removed all film from the cameras, checked to be sure which cameras had operated properly, and noted any improper operation.

Since the processing trailer was located on Elmer, the films from the stations on this island were unloaded immediately and processing was commenced. The processing plan was to develop all films in order of importance, i.e., Rapatronics and Eastman yield films first, so that a quick preliminary analysis could be made. Films from the slower motion-picture cameras, as well as any other glass plates, would then be developed according to size and emulsion.

On Mike shot, because of the unusually wide range of light levels, many of the films were badly under- or overexposed during some portions of interest. Thus each Eastman film was developed individually to make sure that the most information possible was obtained.

As soon as the major films were dry, they were analyzed for a preliminary yield figure. Analysis facilities consisted of a small light box and rewinds built into one end of the photo-trailer and a Hauser Profile Measuring Microscope, Fig. 2.1. Position of burst was also determined here for King shot, and a preliminary report was issued.

After the preliminary analysis work had been done, motion-picture films were shipped to Hollywood for printing before being returned to Boston for final analysis. It should be pointed out that the field processing facilities could handle only black-and-white development, so the final step of converting some footage to color by rehalogenation (Eastman Color Negative) was deferred until EG&G personnel could direct this step at the Air Force Lookout Mountain Laboratory in Hollywood.

The process for preparing a single-topic reel of typical black-and-white films for release was as follows:

Original camera negative was spliced into a convenient roll no longer than about 1000 ft, including perforated identification numbers, gray scales, and graticules. Fine-grain master positive contact prints were made in sufficient number and variation with experimental exposures to allow editing and intercutting of one best standard master. The range of exposures used, sometimes within a few-foot length, was from the least exposure commercially available to more than 40 per cent above the highest standard exposure. Duplicate negative footage was

then generated in camera position to act as printing master for release films and was edited further for the screen.

A titled negative show was then prepared by cutting in slates, credits, maps, and security leader negatives that were separately prepared from field notes. Release prints were issued, after one or two trial prints to ascertain the best screen effects. These were further edited on the basis of the net effect of a whole show and the particular detail it was possible to preserve.

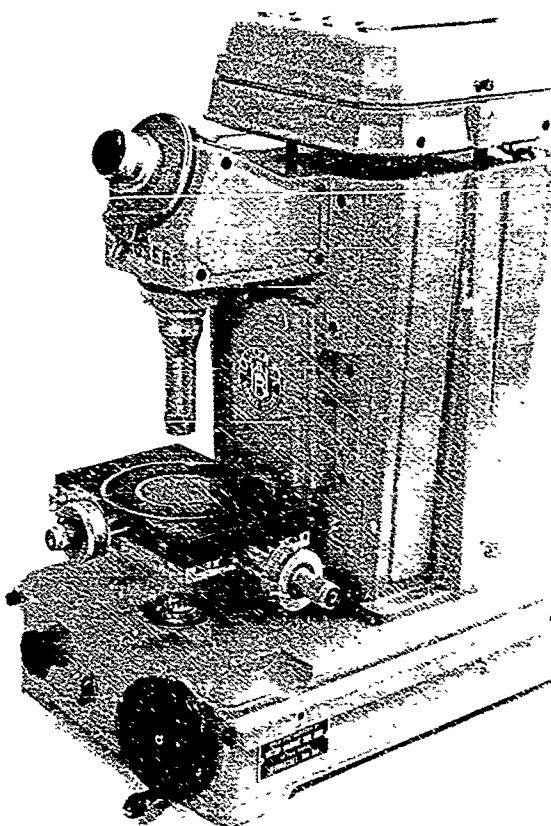


Fig. 2.1—Hauser Profile Measuring Microscope.

at various light levels. (The pictures that are issued are really a copy of a copy of a copy, and the original negatives are never printed for release.)

Preparation for the laboratory and cutting-room work for this operation required the manufacture of titles. Worcester Film Corporation made 75 black-and-white titles for individual film slates, to which were added scale bars to give dimension to the various camera fields of view. EG&G prepared 10 main titles and 12 maps to identify camera purposes, positions, and targets. For Mike and King shots, 800 ft of titles was required.

A cutting room with Movieola and projector was rented from the Hollywood Film Company Editing Film Center. Consolidated Film Industries printed and developed the film. Cinema Research ran two sets of optical prints required for title and scene. On the holidays and week ends, Lookout Mountain Laboratory provided additional space and equipment where security required.

A total of approximately 17,000 ft of release prints was made and released to the interested agencies. Distribution of the various reels is listed in Appendix B.

## CHAPTER 3

### PROJECT 3.1: FIREBALL YIELD DETERMINATION

As on previous operations, fireball diameter was measured from various types of photographic records and plotted as a function of time. These data are used in the determination of the energy release of the nuclear device (so-called fireball scaling) and in the determination of free-air overpressures by the hydrodynamic relations between pressure and shock velocity.

#### 3.1 PROCEDURES

##### 3.1.1 Mike Shot

The techniques necessary for satisfactory photographic coverage of Mike shot were complicated by the gross uncertainty of the expected yield. It was necessary to plan the photographic coverage on the basis of a probable yield of 4.5 MT and on the basis of possible limits of from 50 KT to 40 MT. The primary determination was obtained from six Eastman high-speed cameras located at Station 302, the ground station on Parry Island. Each camera was shielded against fall-out radiation by a factor of approximately 100. Backup photography was provided by a group of 12 unshielded Rapatronic cameras in Station 301, the 125-ft-high Parry phototower.

In order to cover the eventuality of a low-order explosion, a photostation was set up on Engebi (Station 303) with five Eastman high-speed cameras, each shielded against fall-out radiation by a factor of 100. This station was only 19,400 ft from Mike zero as compared to a distance of 114,000 ft for the Parry stations. Three of the Eastman cameras were provided with long-focus lenses to cover the possibility of a low-order detonation; the other two were provided with short lenses to back up the measurements being made from the two Parry stations.

The problem of being able to determine a quick, reliable yield figure, in the event that re-entry to the atoll would be delayed, was met by mounting two Eastman cameras on a stabilized platform on the kingpost of the USS Estes. These cameras were set to run at approximately 1000 frames/sec.

Figure 3.1 shows a typical installation of shielded cameras, in this instance Station 302 on Parry. To position these cameras, they were faced away from Ground Zero, then rotated 90° to a vertical position and mounted on the rear panel of the lead boxes. This method of camera arrangement meant that images received were reversed left to right from the normal image. Mirrors were mounted on the tops of the lead boxes and adjusted to approximately a 45° angle by means of setscrews. Each mirror was held in a closed position by means of a wire; when a predetermined signal was received, the wire burst and a counterweight caused the mirror to open and maintain its correct position. A thick lead-glass plate in the top of the lead box allowed the mirror object image to be viewed by the camera. It was felt that these elaborate

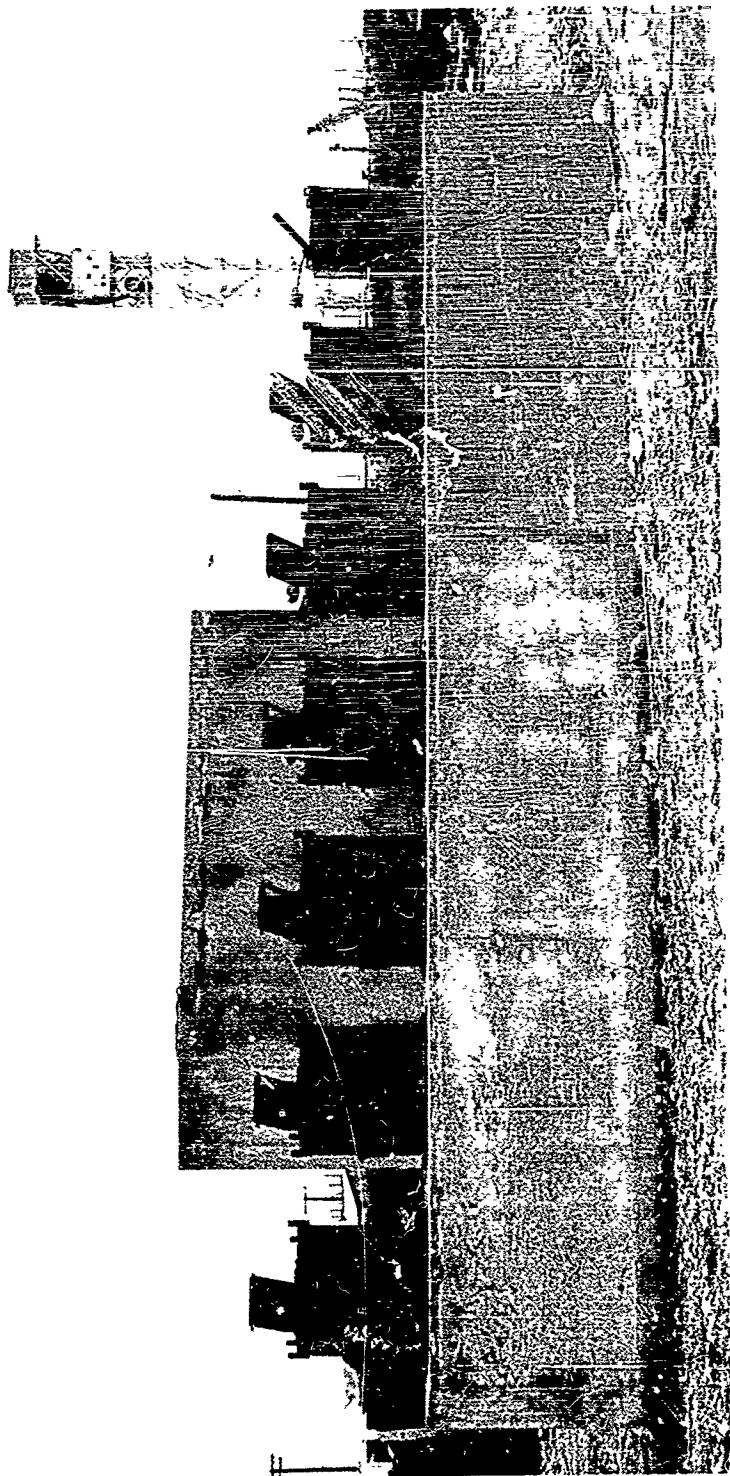


Fig. 3.1.—Shielded-yield-camera installation.

Precautions against damage to the cameras from blast and radiation fall-out were necessary but one of the large element of uncertainty is the behavior of the explosion.

### 3.1.2 King Shot

For King shot the fireball data were to be obtained from Eastman and Rapatronic cameras on Parry. Since King shot was an airdrop, the Eastman cameras were run in three time groups to allow for possible errors in time of fall.

## 3.2 CAMERAS AND EXPOSURES

Data describing the operation of all cameras used on both shots have been issued as Report EG&G-OUT 1517, Ivy Film Data Sheet Catalog, 24 February 1954, and are given in partial form in Appendix D, Camera Data Sheets.

### 3.2.1 Mike Shot

Tables 3.1 and 3.2 summarize the operation of the Eastman and Rapatronic cameras, respectively. The films, in general, suffer from being underexposed owing to the unexpected low

Table 3.1—SUMMARY OF EASTMAN OPERATION, MIKE SHOT

Camera No.	Film No.	Station	Effective aperture	Speed at zero, frames/sec	Horizontal field, meters	Remarks
E20	16101	302	4		3060	No timing marks
E15	16102	302	8	2280	3060	
E12	16103	302	18	2180	3060	
E18	16104	302	2.7	1055	3060	Best record for minimum
E24	16105	302	12			Did not run
E10	16106	302	40			Did not run
E16	16107	303	5.6	2090	525	
E9	16108	303	1	2760	525	
E25	16109	303	80	2570	525	
E27	16110	303	5.6	2580	2100	
E11	16111	303	1	2560	2100	
E26	16112	USS Estes	5.6	1240	4950	
E7	16127	USS Estes	5.6	1250	8020	

radiant emittance of the fireball. Three of the primary Eastman cameras on Parry ran properly. One camera ran, but the velocity-marker spark failed to give any indication. Two cameras did not run owing to a faulty contactor. Of the three good records, only one was exposed heavily enough to show fireball detail into the minimum. The two high-order backup cameras at Station 303 ran properly and yielded useful records. Both Eastman cameras on the USS Estes operated properly, although one was slightly misaimed.

One Rapatronic camera failed because of a faulty mechanical capping shutter, and three others triggered satisfactorily but do not show images owing to underexposure. One camera, R19, evidenced a faulty time delay.

### 3.2.2 King Shot

Tables 3.3 and 3.4 summarize the operation of the Eastman and Rapatronic cameras, respectively. The six Eastman cameras used on King shot to record fireball data were 100 per cent satisfactory in operation. Because of the staggered time sequence of operation, only four

Table 3.2—SUMMARY OF RAPATRONIC OPERATION, MIKE SHOT

Plate No.	Emulsion*	Exposure time, $\mu$ sec	Time, msec	Background density	Image density	Remarks
16141	HRHS	4	0.028			Capping-shutter failure
16142	MF	4	0.101	0.50		Underexposed
16143	MF	4	0.305	0.50		Underexposed
16144	MF	4	0.910	0.38		Underexposed
16145	MF	4	2.98†	0.50	0.62	
16146	HRHS	4	10.3	1.75	2.00	Only skirt of fireball is imaged
16147	HRHS	4	20.2	1.00	1.20	Only skirt of fireball is imaged
16148	Tri X	4	39.5	0.30	0.32-0.65	Bright skirt, faint top
16149	Tri X	40	68.8	0.30	1.03	Excellent picture
16150	Tri X	40	35.0‡	0.29	1.04-1.50	Bright skirt, faint top
16151	Tri X	40	153.0	0.28	0.33-0.41	
16152	Tri X	40	205.3	0.30	0.32	Very faint image

\* The sensitometric characteristics of these emulsions have been presented in Ball-of-fire Observations, Greenhouse Report, Annex 1.4, WT-101.

†The fireball diameter is not consistent with this time of operation, and it is concluded that the time delay was faulty.

‡Salt water leaking through the tower-cab roof altered the delay of this camera from its set-in value of 103.5 to 35.0 msec, as measured after the shot.

Table 3.3—SUMMARY OF EASTMAN OPERATION, KING SHOT

Camera No.	Film No.	Time sequence	Effective aperture	Speed at zero, frames/sec	Horizontal field, meters	Remarks
E20	16201	First	4	3050	1480	
E15	16202	First	8	2870	1480	
E12	16203	Second	4	1295	1480	Best record at minimum
E18	16204	Second	8	1820	1480	
E24	16205	Third	5.6		1480	Started after zero
E10	16206	Third	11		1480	Started after zero

cameras show the initial burst and fireball growth. Twelve Rapatronic cameras were used, and all show images. Five of these (in the interval 0.1 to 10 msec) give good measurable images, four others are too weak to read, and the remaining three clearly show the fireball after shock separation and minimum time. These last three cameras show interesting pictures, but they are not useful for fireball scaling. Camera R19 again evidenced a faulty time delay.

It had originally been intended to operate all Rapatronic cameras in the time range prior to minimum time, but, owing to the lack of time between shots, it was not possible to change the time delay of the cameras from their Mike shot settings. For this reason Rapatronic data suitable for scaling were not obtained.

Table 3.4—SUMMARY OF RAPATRONIC OPERATION, KING SHOT

Plate No.	Emulsion*	Exposure time, $\mu$ sec	Time, msec	Background density	Image density	Remarks
16241	HRHS	4	0.028	0.13	0.16	Weak image
16242	MF	4	0.101	0.10	0.15	Weak image
16243	MF	4	0.305	0.10	0.63	Good image
16244	MF	4	0.910†	0.10	0.32	Good image
16245	HRHS	4	2.98	0.15	1.24	Good image
16246	HRHS	4	10.3	0.11	0.45	Good image
16247	HRHS	4	20.2	0.11	0.15-0.23	Weak image‡
16248	Tri X	4	39.5	0.28	0.28-0.48	Weak image‡
16249	Tri X	40	68.8	0.32	0.34-0.39	Weak image
16250	Tri X	40	103.5	0.29	0.85	After minimum
16251	Tri X	40	153.0	0.29	1.08	After minimum
16252	Tri X	40	205.3	0.28	0.30-0.38	After minimum

\* The sensitometric characteristics of these emulsions have been presented in Ball-of-fire Observations, Greenhouse Report, Annex 1.4, WT-101.

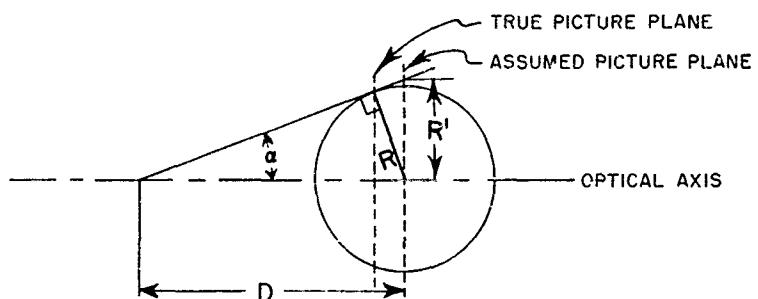
†The fireball diameter is not consistent with this time of operation, and it is concluded that the time delay was faulty.

‡Core brighter than periphery.

### 3.3 FIREBALL DIAMETER-TIME CHARACTERISTICS

The basic elements that go into the precise determination of fireball diameter-time characteristics are the selection, processing, and subsequent handling of a photosensitive emulsion; the maintenance and operation of camera and control circuits; the determination of space and time scales; the accurate measurement of the images; and the mathematics of data analysis. The techniques used in Operation Ivy were essentially identical to those employed in Operation Tumbler-Snapper with the following important differences.

1. Owing to the large minimum time of both Mike and King shots, it is not necessary to calculate an accurate zero-time correction for the first frame of an Eastman record.
2. The Eastman cameras at the ground station on Parry (Station 302) could not see the ground at the shot island owing to curvature and refraction. In measuring the fireballs it was assumed that the surface was hemispherical and matched concentric circles on the reading comparator to the upper portion of the fireball that could be seen above the horizon.
3. The size of the Mike fireball was significant compared to the distance of the fireball from the Eastman cameras at Engebi (Station 303). The effect of this is that the magnification factor changes with fireball size. This effect was compensated for by introducing a correction factor, the maximum magnitude of which was about 2 per cent. The correction is calculated as follows:



Let  $D$  = distance from camera to center of fireball (on the assumption that the optical axis points at the center of the fireball)  
 $f$  = focal length of optical system  
 $R$  = true radius of fireball  
 $R'$  = incorrect radius of fireball, calculated without correction  
 $M$  = magnification =  $D/f$   
 $r = R/M$  = fictitious image radius corresponding to true fireball radius  
 $r' = R'/M$  = measured image radius  
 $\tan \alpha = R'/D = r'/f$  = tangent of measured semiangle

The angle  $\alpha$  is essentially determined from measurements on the film. If it is assumed that the picture plane was a distance  $D$  from the camera, the fireball radius would be  $R'$ . The true radius is  $R$ . The relation between  $R$  and  $R'$  is as follows:

$$R = D \sin \alpha \quad (3.1)$$

$$R' = D \tan \alpha \quad (3.2)$$

Therefore

$$\frac{R}{R'} = \frac{r}{r'} = \cos \alpha = \left[ 1 + \left( \frac{r'}{f} \right)^2 \right]^{-\frac{1}{2}} \quad (3.3)$$

This correction factor is employed to correct the Engebi measurements for the effect of camera proximity.

All measurements and calculations from the various Eastman records have been published in detail in EG&G Report 1083, Ivy Fireball Diameter-Time Characteristics. However, a summary plot of fireball diameter vs time for Mike shot is presented in Fig. 3.2 and for King shot in Fig. 3.3. Tables 3.5 and 3.7 give the same data in tabular form. Diameter measurements from Rapatronics are shown in Tables 3.6 and 3.8.

#### 3.4 FIREBALL SCALING

The techniques of scaling yields of nuclear detonations by means of the fireball diameter-time relation have been discussed in the various ball-of-fire reports for previous operations. We shall, therefore, only treat the subject superficially here.

The general diameter-time relation is of the form

$$D = Kt^n \quad (3.4)$$

The parameter  $\phi$  is defined as the proportionality constant in Eq. 3.4 when the exponent  $n$  is equal to 0.4.

$$D = \phi t^{0.4} \quad (3.5)$$

In the time interval where  $r = 0.4$ , the yield is proportional to the fifth power of  $\phi$ . It has been shown in previous work on fireball scaling that the yield may be determined from the relation

$$W = 1.294 \times 10^{-8} \rho \phi^5 \quad (3.6)$$

where  $W$  = total energy release, kilotons

$\rho$  = air density at burst, grams per liter

$\phi$  = average value of diameter (meters)/time<sup>2/5</sup> (milliseconds) for all films (averaged over the region of 0.4 slope)

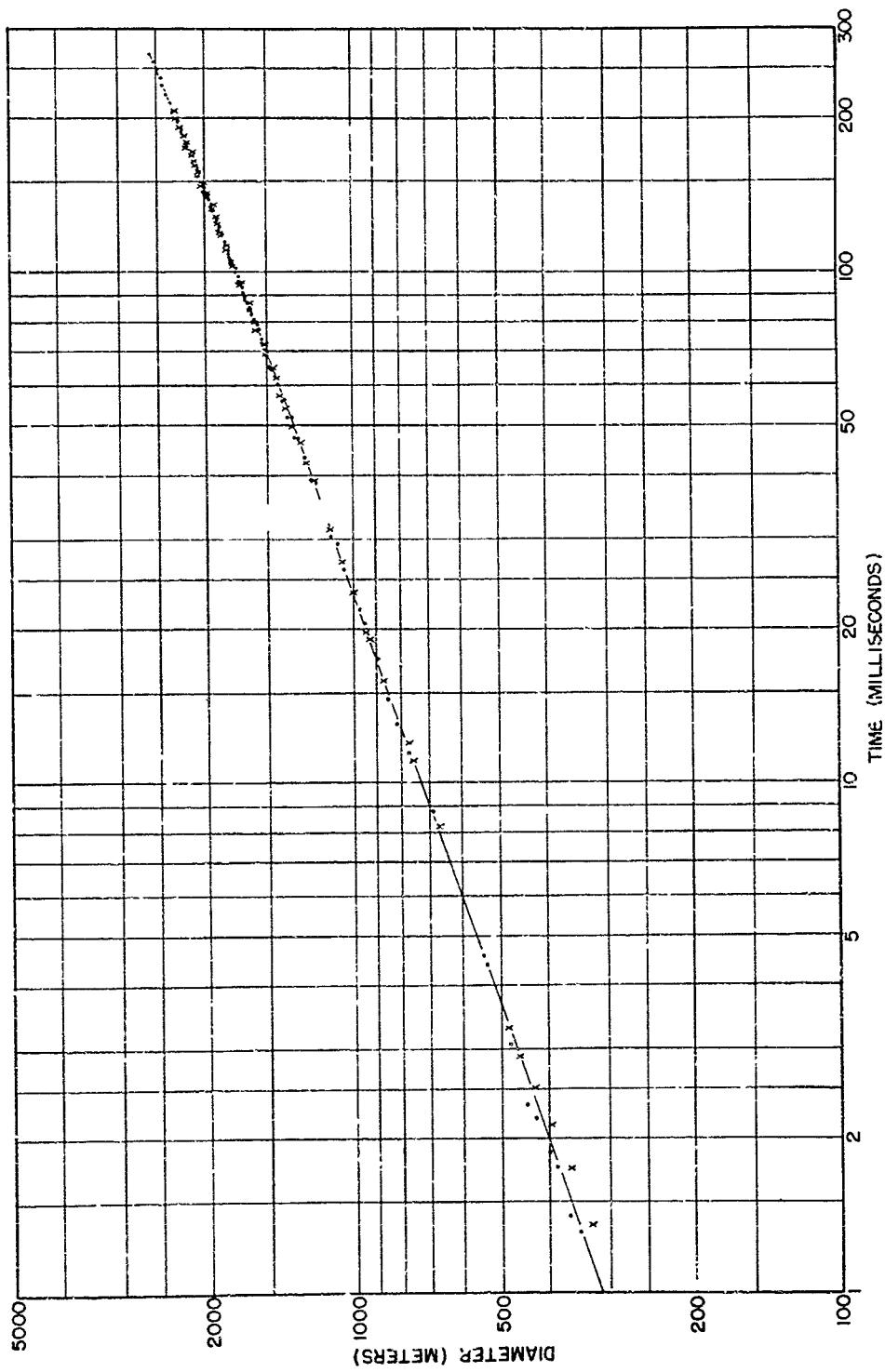


Fig. 3.7.—Fireball diameter vs time, Mike shot. Station 302 records (x = 16,102-16,104) and Station 303 records (x = 16,109-16,111).

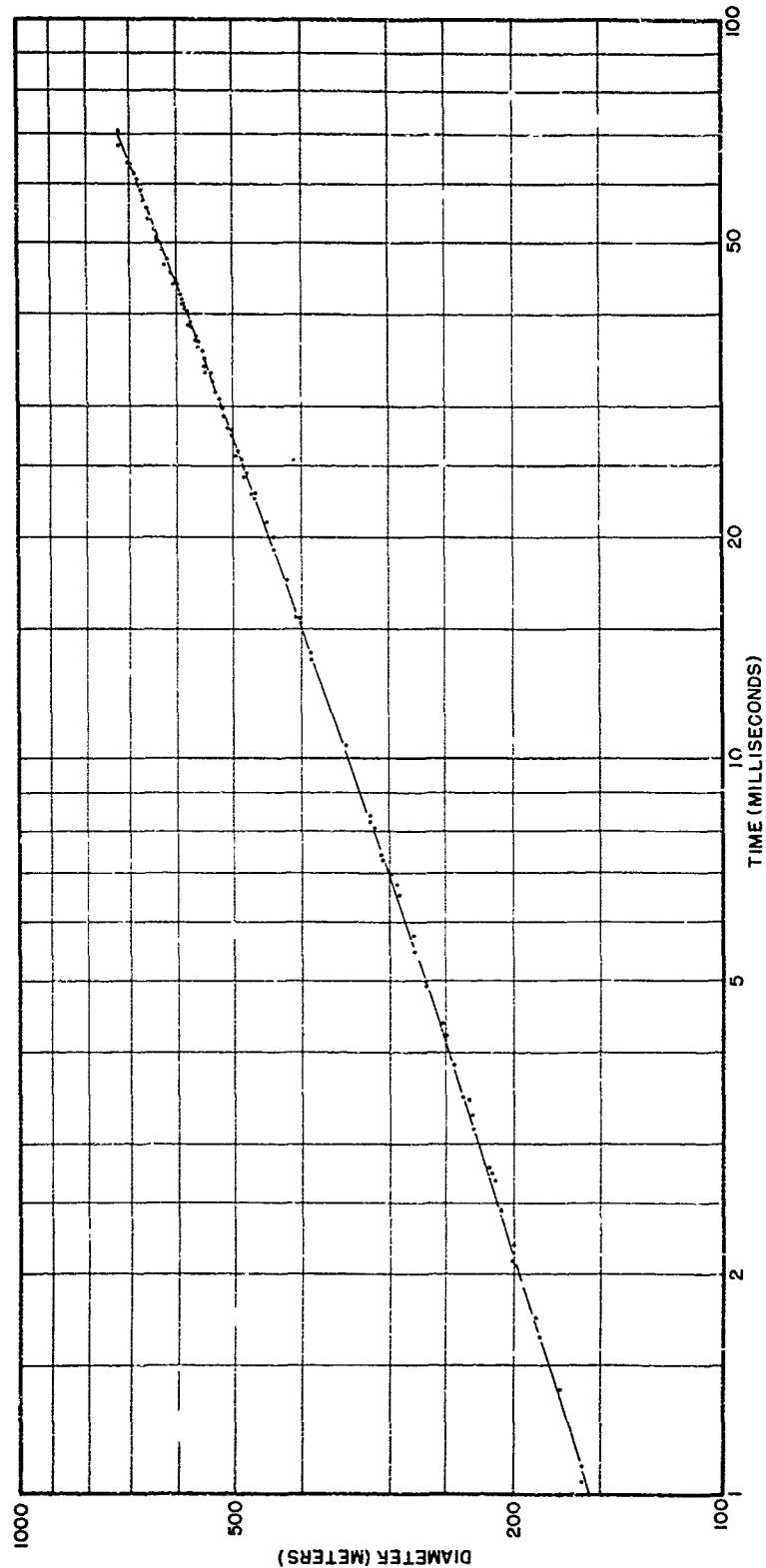


Fig. 3.3.—Fireball diameter vs time, King shot. Station 302 records 16,201-16,204.

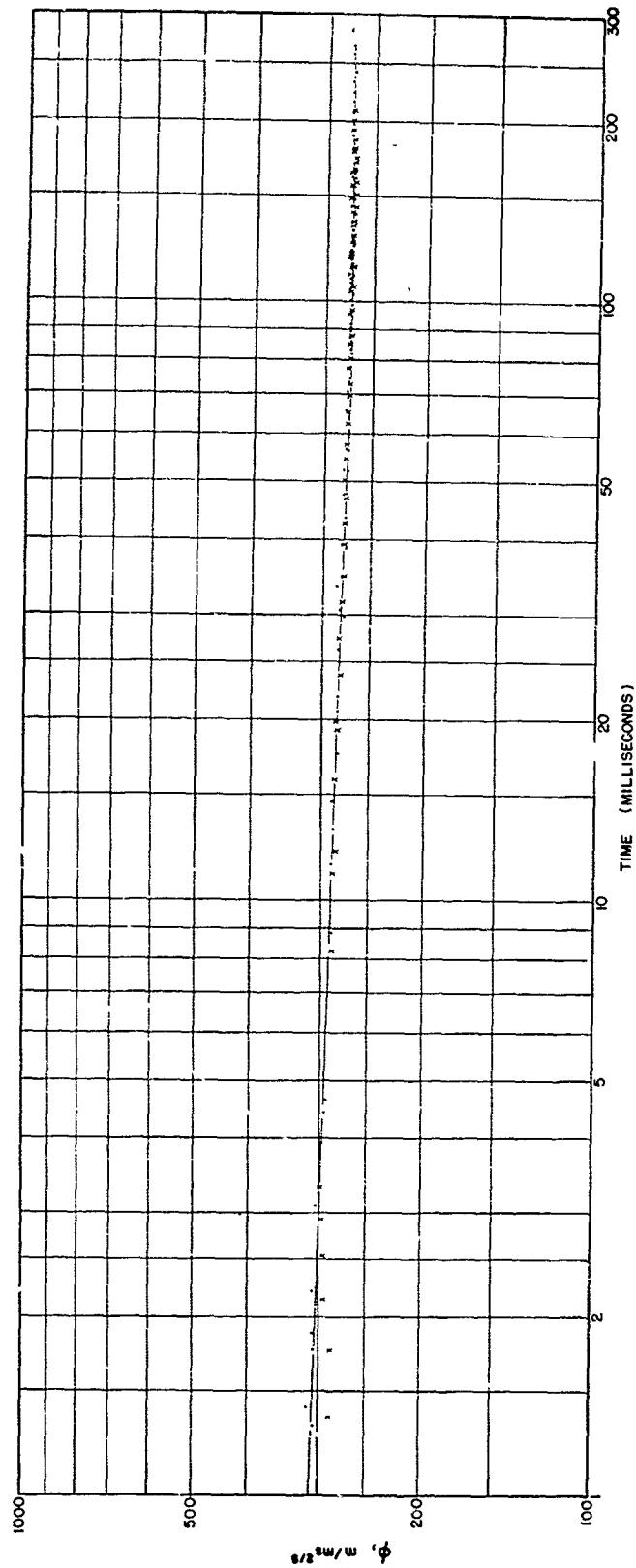


Fig. 3.4— $\phi$  vs time, Mike shot. Station 302 records ( $\cdot$  = 16,102—16,104) and Station 303 records ( $\times$  = 16,109—16,111).

Table 3.5—FIREBALL DIAMETER AS A FUNCTION OF TIME, MIKE SHOT

Time, msec	Diameter, meters
1	311
2	402
5	563
10	728
20	941
50	1320
70	1492
100	1721
150	2024
200	2271
250	2482

Table 3.6—FIREBALL DIAMETER AS A FUNCTION OF TIME FROM RAPATRONICS, MIKE SHOT

Plate No.	Time, msec	Diameter, meters
16145	2.98*	425
16146	10.3	700
16147	20.2	916
16148	39.5	1202
16149	68.8	1492
16150	35.0	1143
16151	153.0	2036
16152	205.3	2320

\*This time is suspect.

Table 3.7—FIREBALL DIAMETER AS A FUNCTION OF TIME, KING SHOT

Time, msec	Diameter, meters
1	155
2	195
5	266
10	342
20	441
40	577
60	679
70	722

Table 3.8—FIREBALL DIAMETER AS A FUNCTION OF TIME FROM RAPATRONICS, KING SHOT

Plate No.	Time, msec	Diameter, meters
16242	0.101	70.8
16243	0.305	98.7
16244	0.910	138
16245	2.98*	212
16246	10.3	344
16250	103.5	737
16251	153.0	883

\*This time is suspect.

Table 3.9— $\phi$  AS A FUNCTION OF TIME, MIKE SHOT

Time, msec	$\phi$ , meters/msec <sup>3/2</sup>
1	311
2	305
5	296
10	290
20	284
50	276
70	272.8
100	272.8
150	272.8
200	272.8
250	272.8

Table 3.10— $\phi$  AS A FUNCTION OF TIME FROM RAPATRONICS, MIKE SHOT

Plate No.	Time, msec	$\phi$ , meters/msec <sup>3/2</sup>
16145	2.98*	275
16146	10.3	275
16147	20.2	275
16148	39.5	276
16149	68.8	275
16150	35.0	276
16151	153.0	272
16152	205.3	276

\*This time is suspect.

The average value of  $\phi$  in the region of 0.4 slope is obtained simply and accurately by arithmetical averaging since  $\phi$  is constant in this region.

### 3.4.1 Mike Shot

The  $\phi$  vs time data for Mike shot are presented in Fig. 3.4 and in Table 3.9. The  $\phi$  data as calculated from the Rapatronic pictures are presented in Table 3.10.

From Fig. 3.4 and Table 3.9 it is seen that the value of  $\phi$  in the region of constant  $\phi$  ( $t \geq 60$  msec) is equal to 272.8 for Mike shot. The yield can be determined from Eq. 3.6 with a modification due to the fact that the device was detonated on the ground and that the energy was concentrated in a hemisphere.

Because of the large size of the Mike fireball, it was felt that an average air density over the entire fireball should be used rather than the simple value of air density at burst height which suffices for smaller detonations. It was therefore decided to use the density of air at the center of gravity of the hemisphere, or 0.3473 times its radius. This radius was chosen at the time  $t$  which is the logarithmic midpoint of the constant  $\phi$  region ( $t = \sqrt{t_1 \times t_2}$ ). At this time (127 msec) the radius was 3051 ft, giving a center of gravity of 1060 ft above ground. The air density at this level was 1.118 g/liter. Scaling was then accomplished according to Eq. 3.6 with an added factor of 0.5, prompted both by theoretical considerations of surface shots and by experience on Jangle J shot. Therefore

$$W = \frac{1}{2}(1.294 \times 10^{-8})(1.118)(272.8)^5 = 10,900 \text{ KT}$$

The method of calculating the probable error in yield of detonations exhibiting a region of growth of constant  $\phi$  has been explained in detail in Greenhouse Report WT-101, Ball-of-fire Observations. One considers only the data in the region of constant  $\phi$  and calculates the standard deviation of a single reading from the average  $\phi$  for the particular film. By weighting these values according to the number of readings made of a film, one can calculate the standard deviation of a single reading considering all films as the population. It is preferable to perform this calculation in two steps since there are errors in the magnification and time scales and it is not correct to assume that all films are from the same population. By dividing the standard deviation of one reading for all films by the square root of the number of film readings considered in the determination of the average  $\phi$ , one determines the deviation of this average value of  $\phi$ ,  $\bar{\sigma}_\phi$ . Additional errors are introduced by systematic errors, such as film shrinkage, errors in magnification of the reading comparator, and errors in the calculated optical-axis distances. We assign a standard deviation of 0.2 per cent to these errors. We also assign a standard deviation of 0.1 per cent to systematic errors in focal length.

There is also an additional error due to possible errors in the evaluation of air density to which we assign a standard deviation of 0.5 per cent. The yield is proportional to the fifth power of  $\phi$  and the first power of air density. Thus the standard deviation of the yield measurement is expressed by

$$\begin{aligned}\sigma_{\text{yield}}^2 &= 25 [\bar{\sigma}_\phi^2 + (0.2)^2 + (0.1)^2] + (0.5)^2 \\ &= 25 \bar{\sigma}_\phi^2 + 1.50\end{aligned}$$

and the probable error is

$$PE_{\text{yield}} = \pm 0.67 \sqrt{25 \bar{\sigma}_\phi^2 + 1.50} \quad (3.7)$$

The data from which the probable error in the yield of the Mike shot is calculated are presented in Table 3.11.

It is believed that a probable error in yield of  $\pm 0.8$  per cent is smaller than the real probable error owing to (1) possible uncertainties in the factor of 2, introduced to take account of ground reflection, (2) possible errors in the scaling law in this yield range, and (3) possible ef-

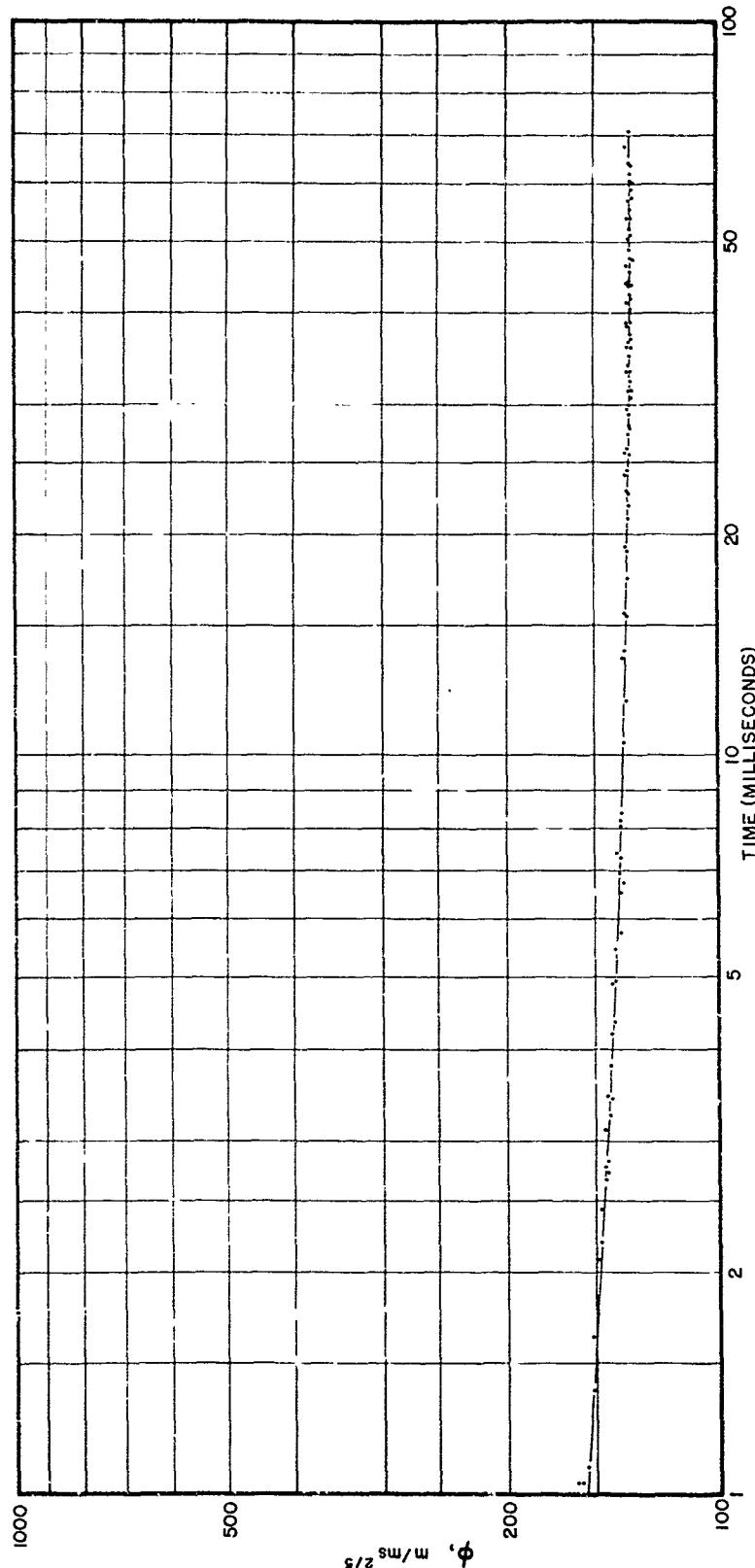


Fig. 3.5— $\phi$  vs time, King shot. Station 302 record: 16,201—16,204

Table 3.11—STATISTICAL ANALYSIS OF MIKE FIREBALL DATA

Film No.	$\bar{\phi}$	No. readings, time >60 msec	$\Sigma(\phi - \bar{\phi})^2$ , %	$\bar{\sigma}_{\phi}^2$ , %	Probable error in yield, %
16111	272.6	20	13.45		
16110	271.9	16	20.75		
16104	273.6	17	8.66		
16103	273.9	14	7.08		
16102	272.1	26	24.48		
		$\Sigma = 93$		0.0091	$\pm 0.82$

Table 3.12— $\phi$  AS A FUNCTION OF TIME, KING SHOT

Time, msec	$\phi$ , meters/msec <sup>3/2</sup>
1	155
2	148
5	140
10	136
20	133
40	132.0
60	132.0
70	132.0

Table 3.13— $\phi$  AS A FUNCTION OF TIME FROM RAPATRONICS,  
KING SHOT

Plate No.	Time, msec	$\phi$ , meters/msec <sup>3/2</sup>
16242	0.101	177
16243	0.305	159
16244	0.910	143
16245	2.98*	137
16246	10.3	135
16250	103.5	119.8†
16251	153.0	118.0†

\*This time is suspect.

†After minimum.

Table 3.14—STATISTICAL ANALYSIS OF KING FIREBALL DATA

Film No.	$\bar{\phi}$	No. readings, time >40 msec	$\Sigma(\phi - \bar{\phi})^2$ , %	$\bar{\sigma}_{\phi}^2$ , %	Probable error in yield, %
16201	131.9	15	2.24		
16202	131.9	3	0.56		
16203	131.8	10	6.58		
16204	132.5	3	2.53		
		$\Sigma = 31$		0.0108	$\pm 0.82$

fects resulting from the considerable change in atmospheric pressure, temperature, and density with fireball altitude (4500 ft at time of minimum). We feel that a probable error of  $\pm 5$  per cent is more realistic.

### 3.4.2 King Shot

The  $\phi$  vs time data for King shot are presented in Fig. 3.5 and in Table 3.12.

The  $\phi$  data as calculated from the Rapatronic pictures are presented in Table 3.13.

From Fig. 3.5 and Table 3.12 it is seen that the value of  $\phi$  in the region of constant  $\phi$  is equal to 132.0 for King shot. The yield can be determined from Eq. 3.6 using 1.109 g/liter as air density as given in Appendix C. Therefore

$$W = 1.294 \times 10^{-8} (1.109)(132.0)^5 = 575 \pm 5 \text{ KT}$$

The probable error in yield is determined by means of Eq. 3.7. This calculation is illustrated by Table 3.14. We feel that the statistically derived error is valid in this case since the unknown factors mentioned in the evaluation of the Mike shot errors are much smaller for King shot.

## CHAPTER 4

### PROJECT 3.2: CLOUD RISE

The cloud-rise program, Project 3.2, was devised to supply interested groups with information pertaining to the rate of rise and the various dimensions and height attained by the cloud and stem resulting from the detonation of Mike and King shots. An extensive analysis was made of the photographs obtained on both shots. Results of this analysis appear in EG&G Report 1136, Cloud and Stem Phenomena, Operation Ivy, 23 April 1954. A summary of this report is presented here.

#### 4.1 MIKE SHOT

One C-47 aircraft flew approximately 80 nautical miles to the east of Ground Zero on a south-to-north course at the time of burst at an altitude of 10,000 ft. An A6 35-mm movie camera started at M-15 sec and ran until approximately M+1 min. Pictures were also taken at the rate of one a minute by a hand-held Speed Graphic camera from zero time until M+1 hr; however, no record was obtained at M+1 min. At zero time the aircraft ran into a thunderhead, causing turbulence and poor visibility. Many of the late-stage photographs are of no value owing to interference from normal clouds passing between the plane and the bomb cloud.

A second C-47 was about 68 nautical miles south-southwest of the zero point at zero time, flying a west-to-east course at 12,300 ft. Pictures were taken from this aircraft every minute by a hand-held Speed Graphic from M+1 min to M+1 hr.

In general, the C-47 to the south gave better early coverage, and the later stages were best recorded from the C-47 to the east.

Speed Graphics were also set to record cloud progress at 1-min intervals from the USS Curtiss and the USS Estes. The Curtiss gave a much better group of Speed Graphic records of the Mike cloud than did the Estes. At zero time the Curtiss was 214,000 ft due east of Ground Zero, proceeding at approximately 2 knots on a bearing of 090°. A Speed Graphic was utilized to record a picture of the cloud formation once every minute, as was done in the C-47 aircraft. Only those pictures taken up to about M+10 min proved valuable since the cloud had extended beyond the field of view of the camera by this time.

The USS Estes, which was 184,000 ft south of the zero point, was cruising at 5 knots on a bearing of 150° and a course of 330° at the time of detonation. The intention was to take one photograph every minute with a Speed Graphic, but, owing to the interference from the normal cloud cover, pictures were taken only when a break in the clouds gave a reasonable view of the bomb cloud. Of these films only those taken at M+3 and M+5 min gave valuable information.

Further coverage of the Mike cloud was supplied by three Mitchell 35-mm cameras located on Parry Island. Two low-speed Mitchells were located at Station 308, 115,040 ft from the zero

point, and were set to expose one frame every 2 sec. These records provided a series of highly valuable and spectacular pictures of the stem formation and cloud rise. However, the first 17 frames in each camera were in fogged leader; measurements consequently began at 34 sec.

The third Mitchell, a 100 frame/sec camera, was located at Station 301 (the Parry Island phototower), 114,510 ft from Ground Zero, and provided valuable information on the early stages of the stem and the cloud.

Table 4.1 gives a summary of the photostations used.

Table 4.1—SUMMARY OF PHOTOSTATIONS

Film No.	Camera location	Approximate direction at zero time	Distance from Ground Zero at zero time, ft
Still-camera Stations			
16000	C-47	East	484,000
16010	C-47	South-southwest	415,000
16020	USS Estes	South-southeast	184,000
16030	USS Curtiss	East	214,000
Motion-picture-camera Stations			
16119	Station 308	South-southeast	115,040
16120	Station 308	South-southeast	115,040
16121	Station 301	South-southeast	114,510

#### 4.2 KING SHOT

Photographic coverage of the King cloud consisted of two Speed Graphics, three low-speed 35-mm Mitchell cameras, one high-speed Mitchell, and a manually operated Eastman Cine Special. These cameras were located in a C-47 and at Stations 302 and 308.

A C-47 flying at 10,000 ft on a west-to-east course 30 nautical miles due south of Ground Zero at zero time covered the King cloud. A 48 frame/sec A6 camera ran from zero time until  $K + 45$  sec, and a Speed Graphic recorded at varying intervals from  $K + 1$  min to  $K + 1$  hr. Both of these cameras were hand held.

Cameras were also operated from Stations 302 and 308 on Parry Island. Station 308 contained two low-speed Mitchells for cloud-recording purposes; however, these did not operate owing to power failure before zero time. Station 302 contained one high-speed Mitchell which ran at 140 frames/sec, one Speed Graphic, and one Eastman Cine Special which ran at 24 frames/sec.

On the aerial photographs it was impossible to see any ground reference point, owing largely to the normal cloud-cover interference. However, it was possible to locate a reference point on the cloud stem, visible on both an aerial record and a Parry Island Speed Graphic record. Thus, knowing the altitude of this reference point from the ground photograph provided an altitude determination for the aerial shots. Two such points were located, and the altitude was averaged.

#### 4.3 RESULTS

Because results obtained from the cloud films have been reported in detail elsewhere, only the highlights of the analysis will be mentioned here. The Mike cloud reached its maximum

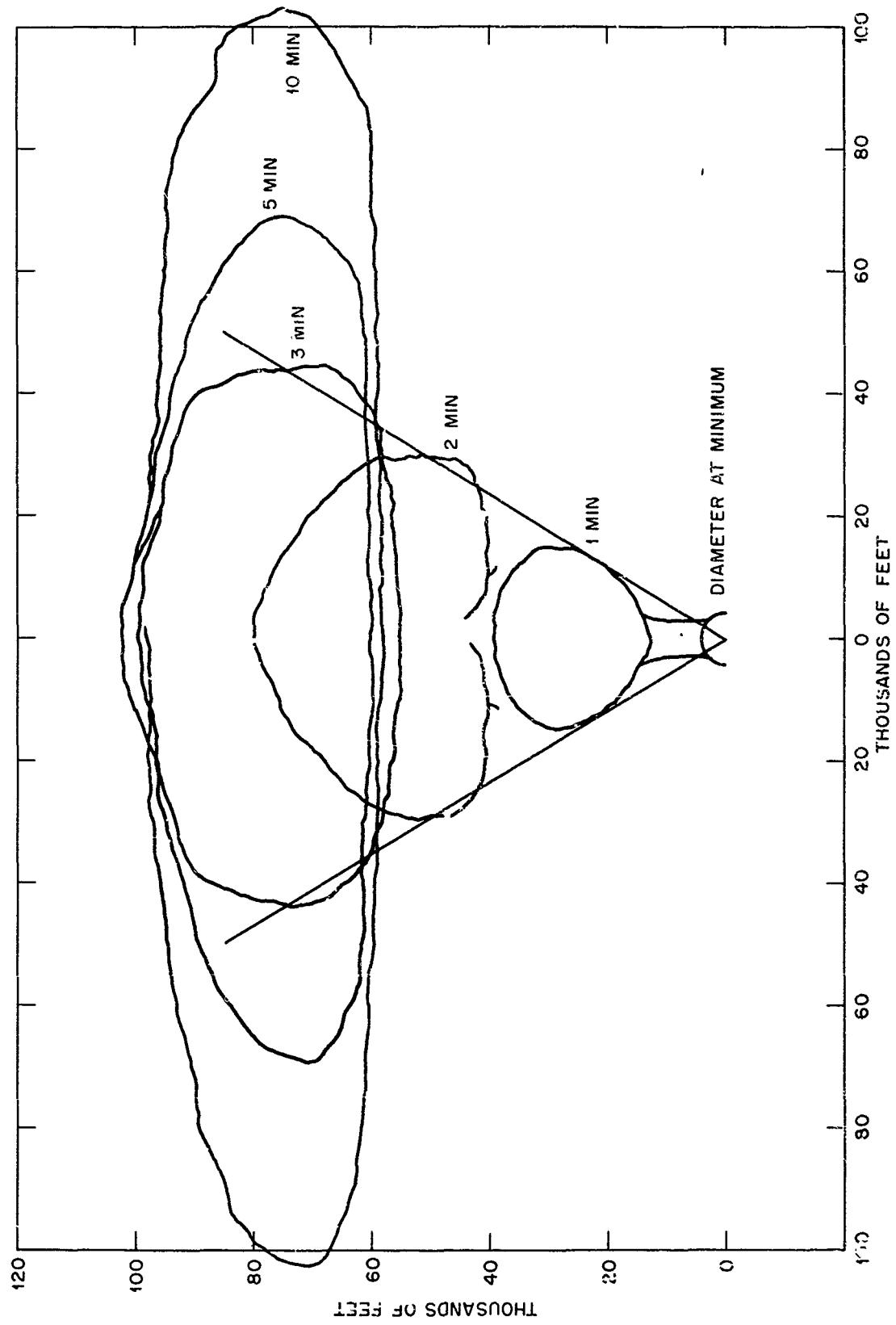


Fig. 4.1—Sketch of cloud form on Mike shot.

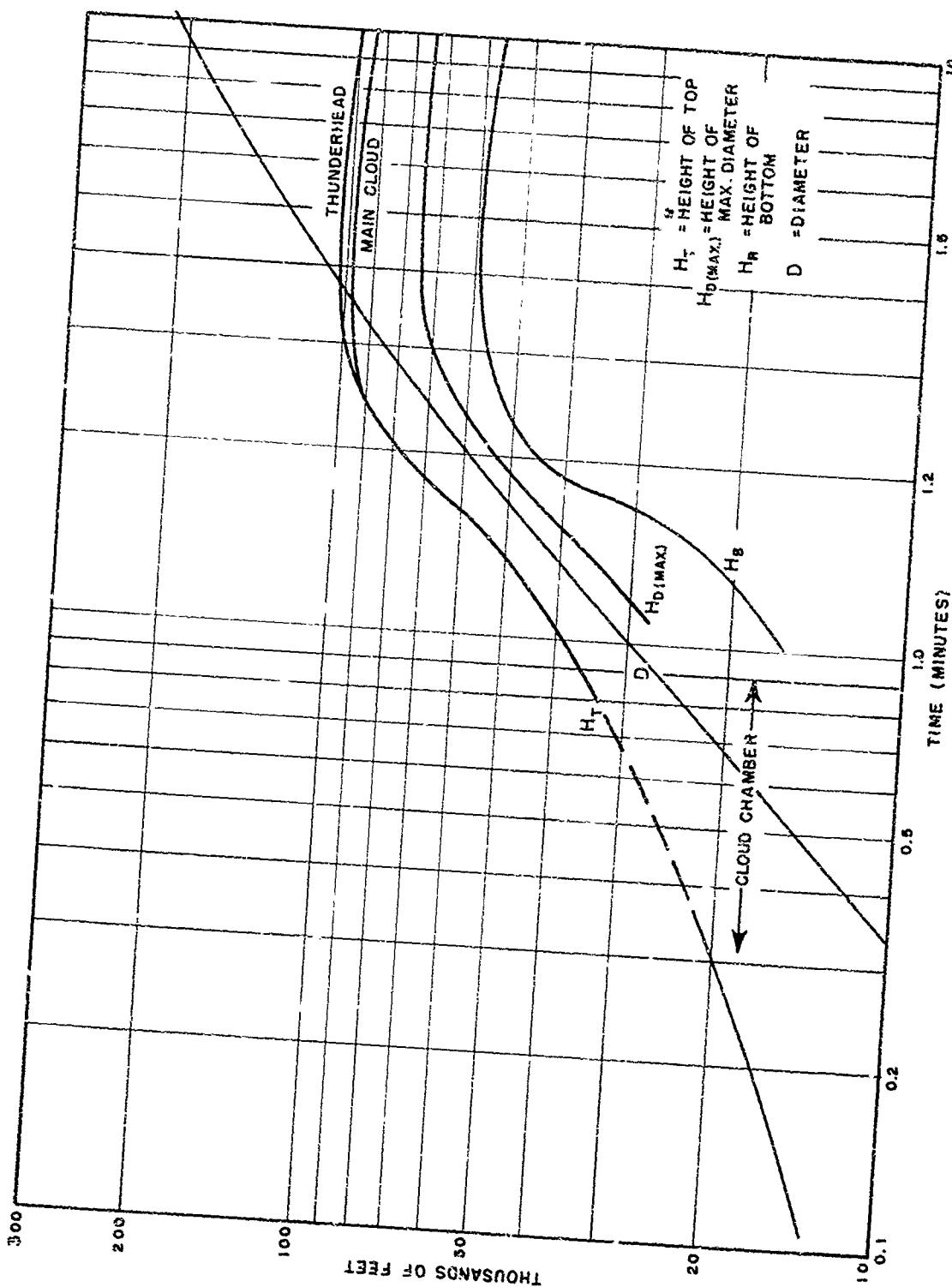


Fig. 4.2.—Diameter and height of Mike cloud as a function of time.



Fig. 4.3—Mike cloud, 1 min. 40 sec.

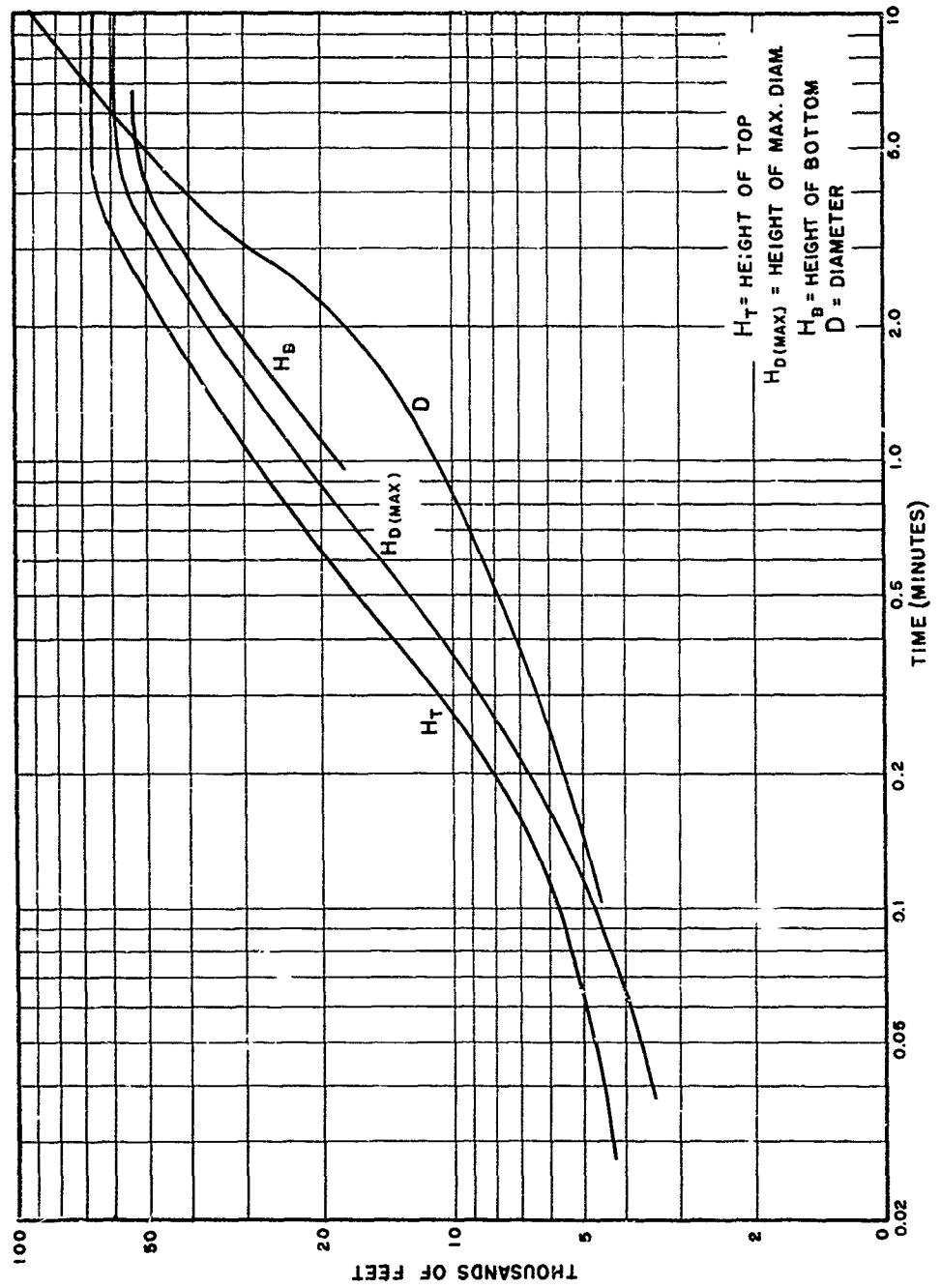


Fig. 4.4—Diameter and height of King cloud as a function of time.

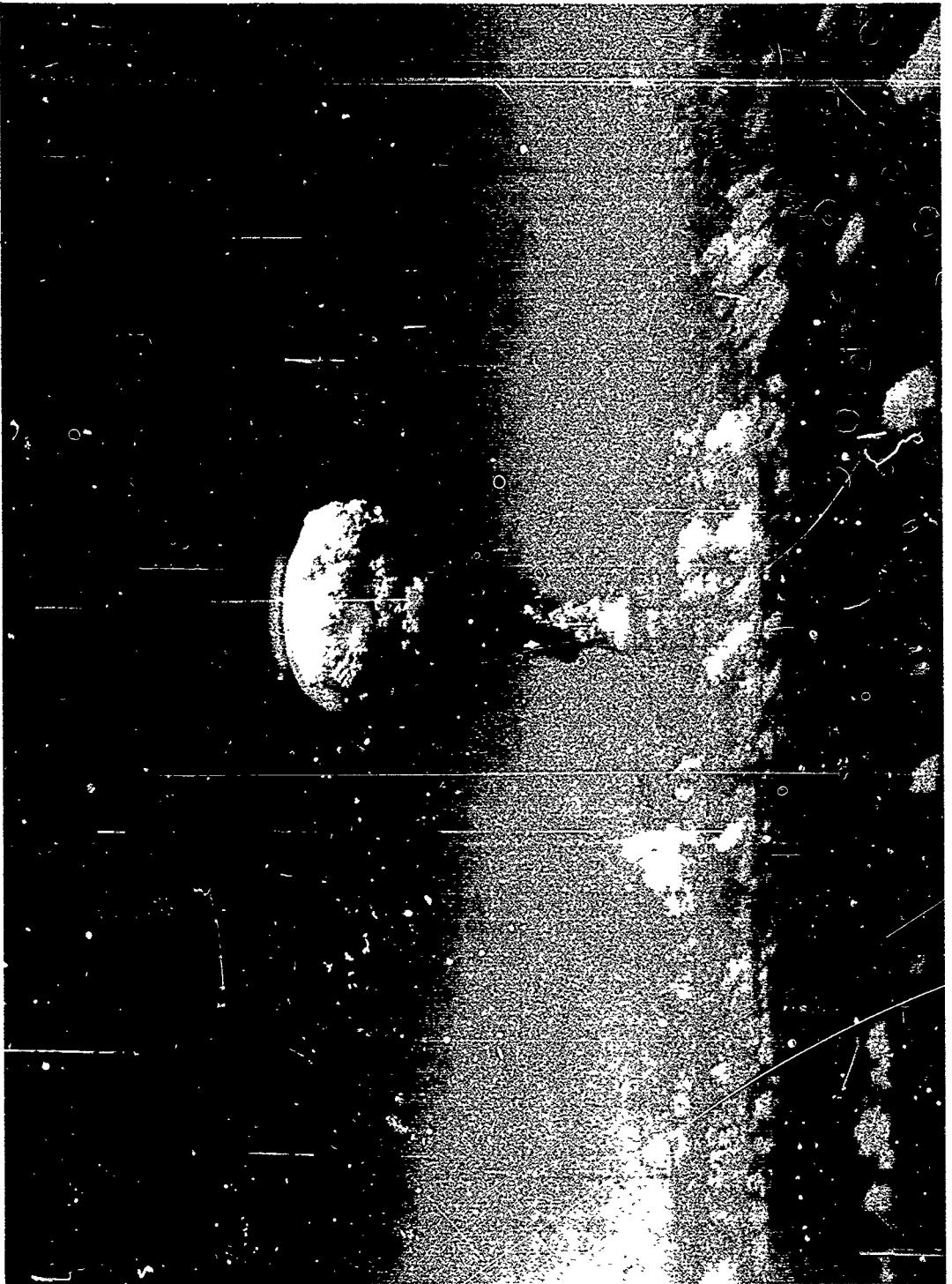


Fig. 4.5—King cloud, 3 min. 20 sec.

height of slightly over 100,000 ft in about 4 min, at which time the diameter had spread to more than 100,000 ft. At the end of 1 hr the cloud had spread out over a range of 300,000 ft. Figure 4.1 sketches the progress of the cloud during the first 10 min. Figure 4.2 shows four curves: maximum diameter, maximum height, height of maximum diameter, and height to bottom of cloud. The curve showing the maximum height of the cloud splits and gives a separate value for the thunderhead as it pushes on above the main cloud. A typical frame from a Parry camera appears in Fig. 4.3.

The King cloud attained its maximum height of 65,000 ft in slightly over 4 min, while growing to a 40,000-ft diameter. Figure 4.4 gives the diameter, height of top, height to bottom, and height of maximum diameter of the cloud throughout a 10-min period. A photograph from the C-47 Speed Graphic, Fig. 4.5, shows the cloud just before it reaches maximum height. The ice cap which formed above the cloud is also clearly visible.

The results as presented should be considered reliable to  $\pm 10$  per cent for 10 min on both shots.

## CHAPTER 5

### PROJECT 3.5: LUMINOUS EMITTANCE VS TIME

Two General Radio slit cameras of the same type used on previous operations, viz., Operations Ranger, Greenhouse, Buster-Jangle, and Tumbler-Snapper, were operated on both shots from Station 301, the Parry phototower. Discussion of the principles and method of operation of these cameras appears in Technical Photography, Buster-Jangle Project 10.3 Report, WT-417. Location and operation of the two cameras were identical for both Mike and King shots, with the exception that the cameras were set for a much slower running speed for King shot because of the uncertainty in expected zero time. Six slit channels were employed on each camera, filtered in even steps from ND-0 (no filter) to ND-3.0 (light attenuated 1000 times). One camera used black-and-white microfile film, whereas the other used Eastman Color Negative in an attempt to record data over a wide spectral band.

Owing to the fact that the light levels were much lower than anticipated on Mike shot, the Eastman Color Negative record blanked out some time before minimum, but the black-and-white film provides a useful record on two channels through the minimum. Neither of the cameras operated on King shot.

As yet, no attempt has been made to analyze the one useful record obtained from Mike shot, owing to the problems of film sensitivity in the various wavelength bands, as outlined in Technical Photography, Tumbler-Snapper Project 12.1 Report, WT-569.

## CHAPTER 6

### PROJECT 3.6: BHANGMETERS, MOD II

Bhangmeters similar to those used on Operations Buster-Jangle & Tumbler-Snapper were used on Ivy. The evaluation of this instrument can be traced through previous reports.<sup>1</sup>

Bhangmeters used on Mike shot incorporated special modifications of the old Bhangmeters in view of the extremely long minimum time expected, the circuit time constants of the standard models being inadequate. Standard units were used on King shot, although new sweep and oscillator parameters were required.

Four Bhangmeters, all using a 110-volt a-c power supply, were operated from the USS Estes on Mike shot. Three of these used 100 cycle/sec marks, and the fourth used 250 cycle/sec marks to cover the eventuality of a possible low-order burst. Only one of the four Bhangmeters triggered, and the time to minimum was so long that this record showed only a continuous decrease in light level beyond the recording time. This record appears in Fig. 6.1.

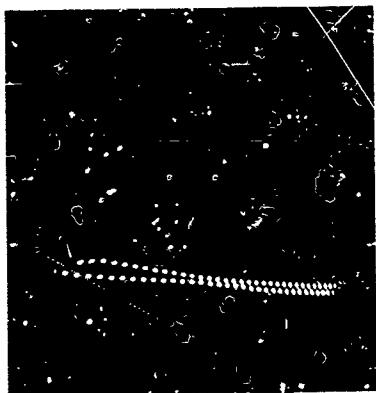
Five Bhangmeters, all operating on 110 a-c volts, were used for King shot, one at Station 302 at the foot of the phototower, two at Station 308, and two in the Parry control room, Station 311. All five of these units gave satisfactory records. Table 6.1 summarizes results obtained from the King shot Bhangmeters. Time to minimum is converted to yield by means of the calibration curve shown in Fig. 6.2, which was obtained with the aid of radiochemical data on Operations Sandstone, Ranger, Greenhouse, Buster-Jangle, and Tumbler-Snapper. King shot Bhangmeter records are reproduced in Fig. 6.1.

Table 6.1—BHANGMETER RESULTS, KING SHOT

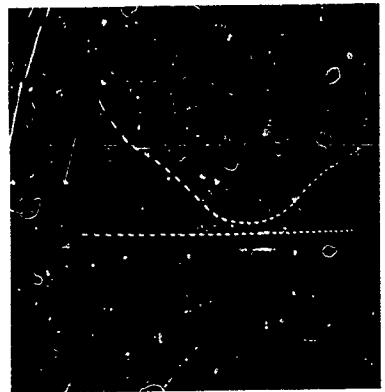
Location	Time to minimum, msec	Bhangmeter yield
Station 308	68	440 ± 90 KT
Station 308	68	440 ± 90 KT
Station 302	68	440 ± 90 KT
Station 311	68	440 ± 90 KT
Station 311	68	440 ± 90 KT

#### REFERENCE

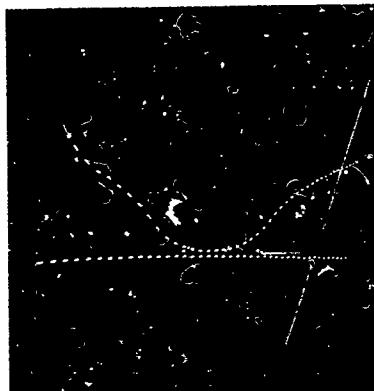
1. Air Drop Instrumentation: Bhangmeter, Greenhouse Report, Annex 1.9, Part I, WT-92; Bhangmeter Mod II, Buster-Jangle Project 10.3b Report, WT-403; Bhangmeter Mod II, Tumbler-Snapper Project 12.1 Report, WT-562.



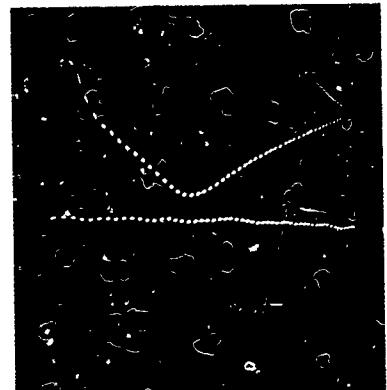
MIKE  $T_{MIN.}$  = UNKNOWN  
USS ESTES



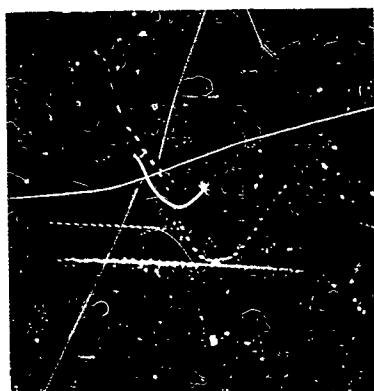
KING  $T_{MIN.}$  = 68ms  
STA. 308



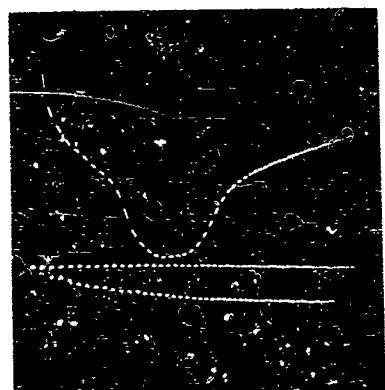
KING  $T_{MIN.}$  = 68ms  
STA. 308



KING  $T_{MIN.}$  = 68ms  
STA. 302



KING  $T_{MIN.}$  = 68ms  
STA. 311



KING  $T_{MIN.}$  = 68ms  
STA. 311

Fig. 6.1—Bhangmeter records, Mike and King shots.

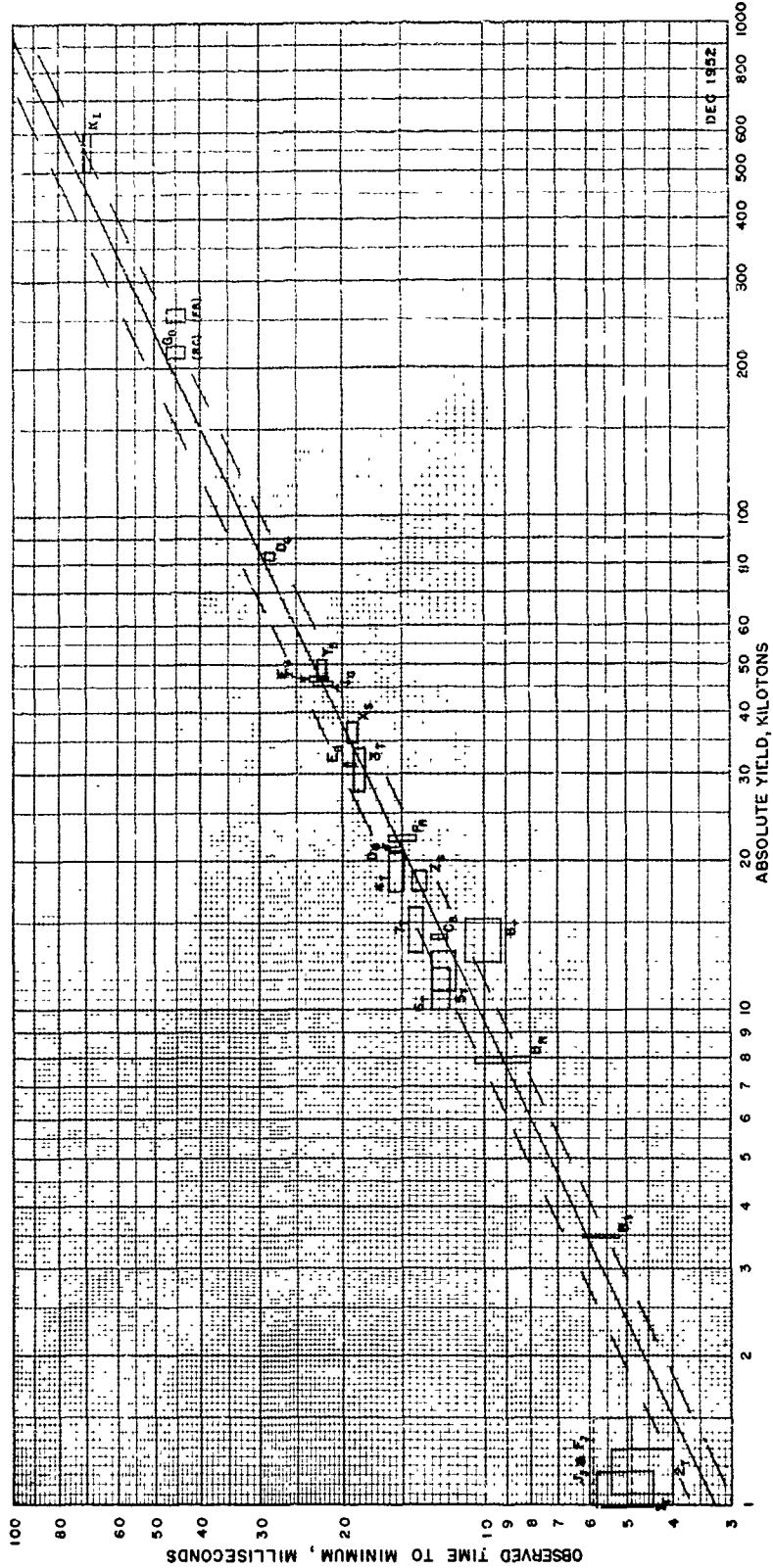


Fig. 6.2—Calibration curve, time to minimum vs yield.

## CHAPTER 7

### PROJECT 3.8: POSITION OF BURST

Position-of-burst determination was required for the King airdrop. One Wild theodolite camera was set up at Station 306 on Rojoa, backed up by a Galileo phototheodolite at the same station. Two Galileo type phototheodolites were set up on the Holmes and Narver (H&N) coral survey station (Station 304) to provide approximately 90° coverage. A second Wild phototheodolite was located at Station 302, the Parry ground station. Figure 7.1 illustrates approximate camera positions. All cameras were equipped with faster shutters than were used on previous operations in an attempt to gain more precise determination, although any gain here would be offset by the greater distances over which the cameras were to operate.

Of the five cameras, only the Wild at Station 302 operated satisfactorily. The others were damaged by rust due to the heavy rains on the days previous to shot day, with consequent jamming of the mechanisms. Triangulation was accomplished using the record from one of the GSAP cameras of the Naval Research Laboratory, aimed at rocket trails from Station Mack, in conjunction with the one good theodolite record.

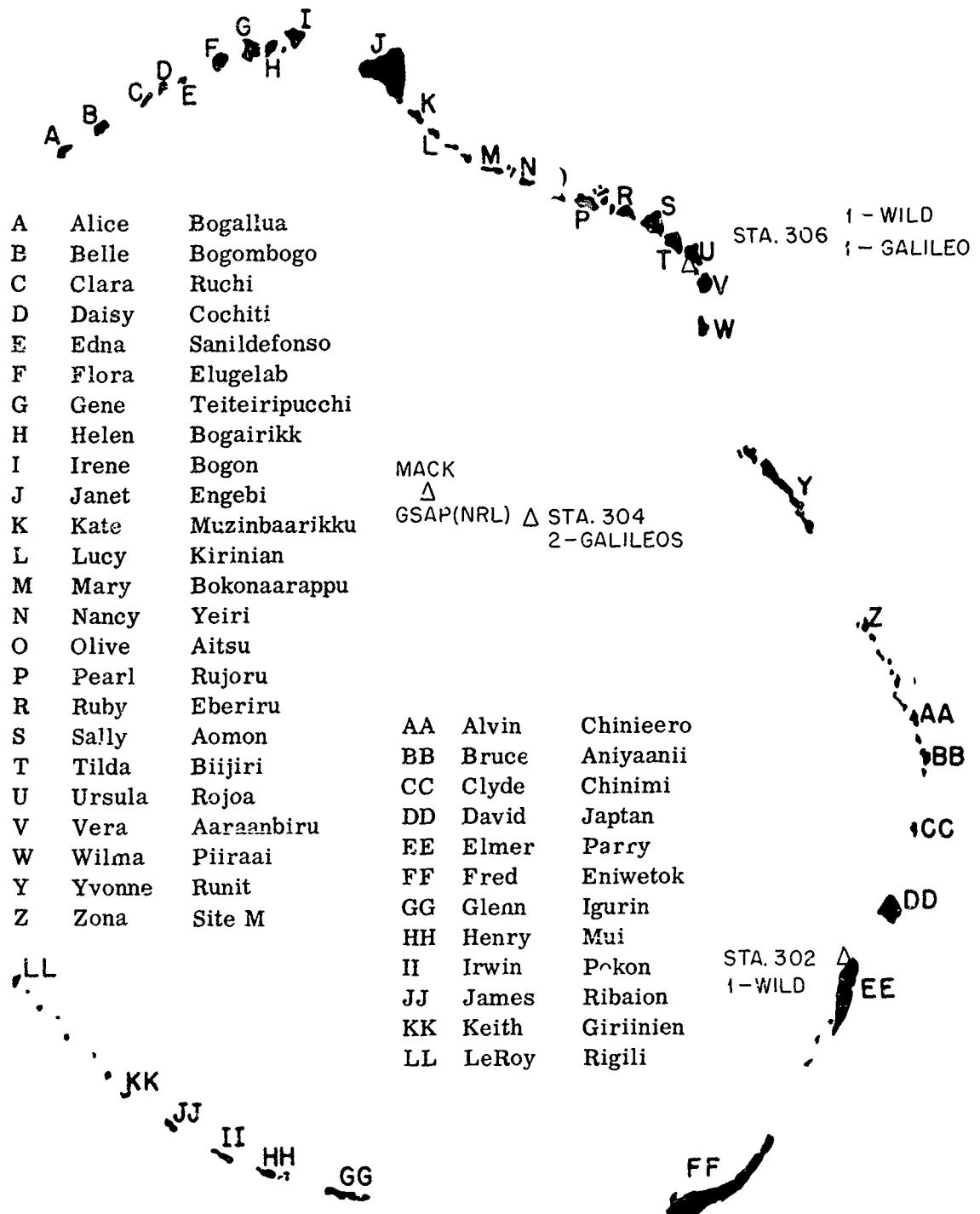
Burst coordinates were determined in a coordinate system using the H&N coral survey station 304 as origin (N 100,000; E 100,000). This station is located at latitude 11°32'20" N and longitude 162°17'11" E. In this system the King burst was determined to be

N 108,450 ± 30'  
E 123,650 ± 20'  
Height: 1480 ± 20 ft above sea level

These coordinates correspond to a value of latitude 11°33'44" N and longitude 162°21'09" E.

Drop error was computed to be

300 ± 30 ft north  
480 ± 20 ft west  
570 ± 30 ft radially



### ENIWETOK ATOLL

Fig. 7.1--Theodolite-camera locations, King shot.

## CHAPTER 8

### PROJECT 6.2: MORTAR AND GUN BURST

As in Operation Tumbler-Snapper, Group J-10 of the Los Alamos Scientific Laboratory (LASL) undertook to measure free-air pressures by observing the motion of smoke-labeled air particles under the influence of the shock wave. For Mike shot, Mitchell high-speed cameras, shielded against fall-out radiation in the same manner as described in Chap. 1, were set up on four different islands to observe the motion of mortar and gun puffs. Each camera viewed two puffs, some of which were at high altitudes (5000-26,000 ft) and others at low altitudes (approximately 400 ft above ground). On King shot, only the low-altitude puffs were used, and all the cameras were located on Rojoa. All cameras operated successfully, and films from this project provide a good record of motion and shock progress.

Figures 8.1 and 8.2 show puff locations and camera fields of view.

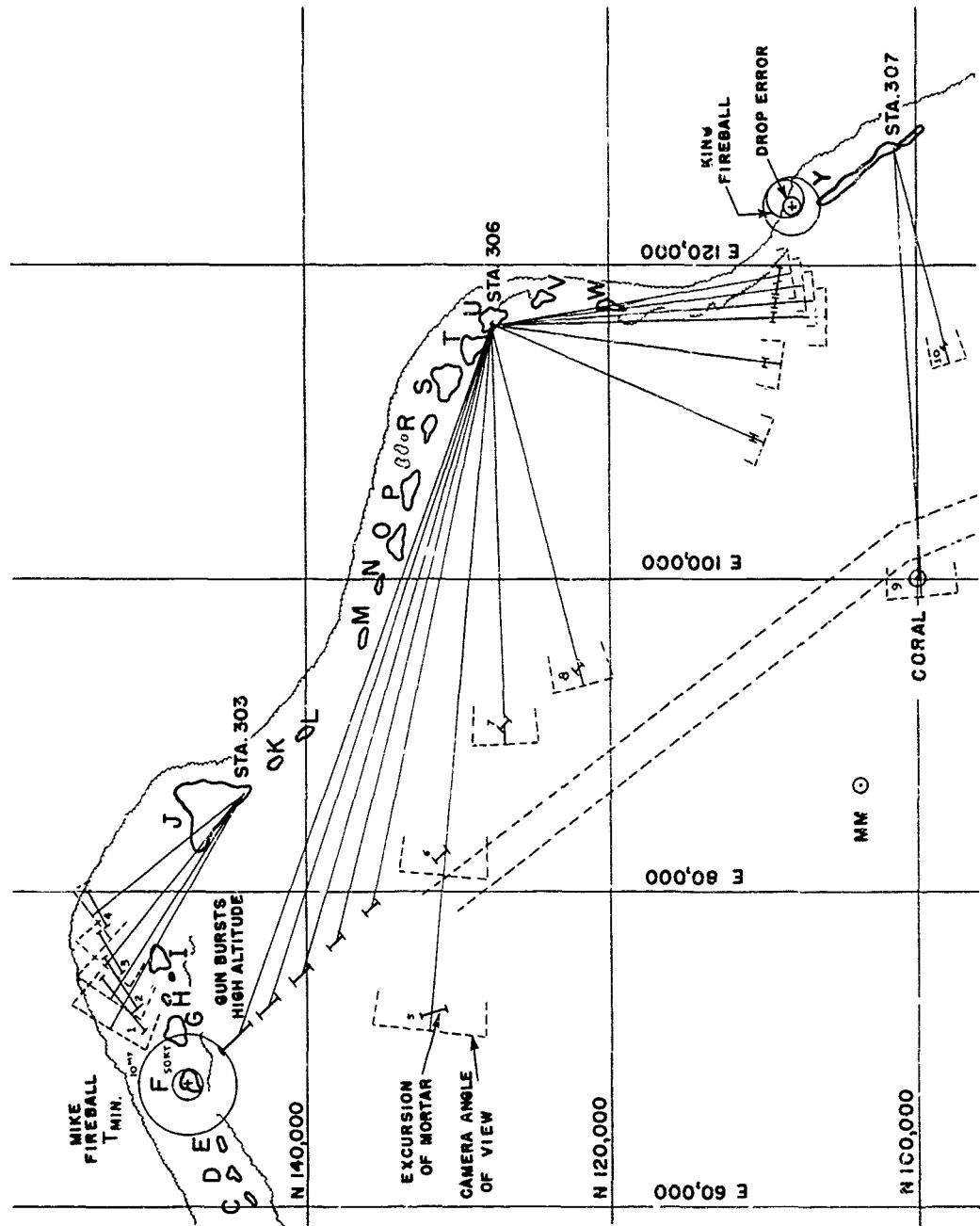


Fig. 8.1.—Mortar-photography camera stations.

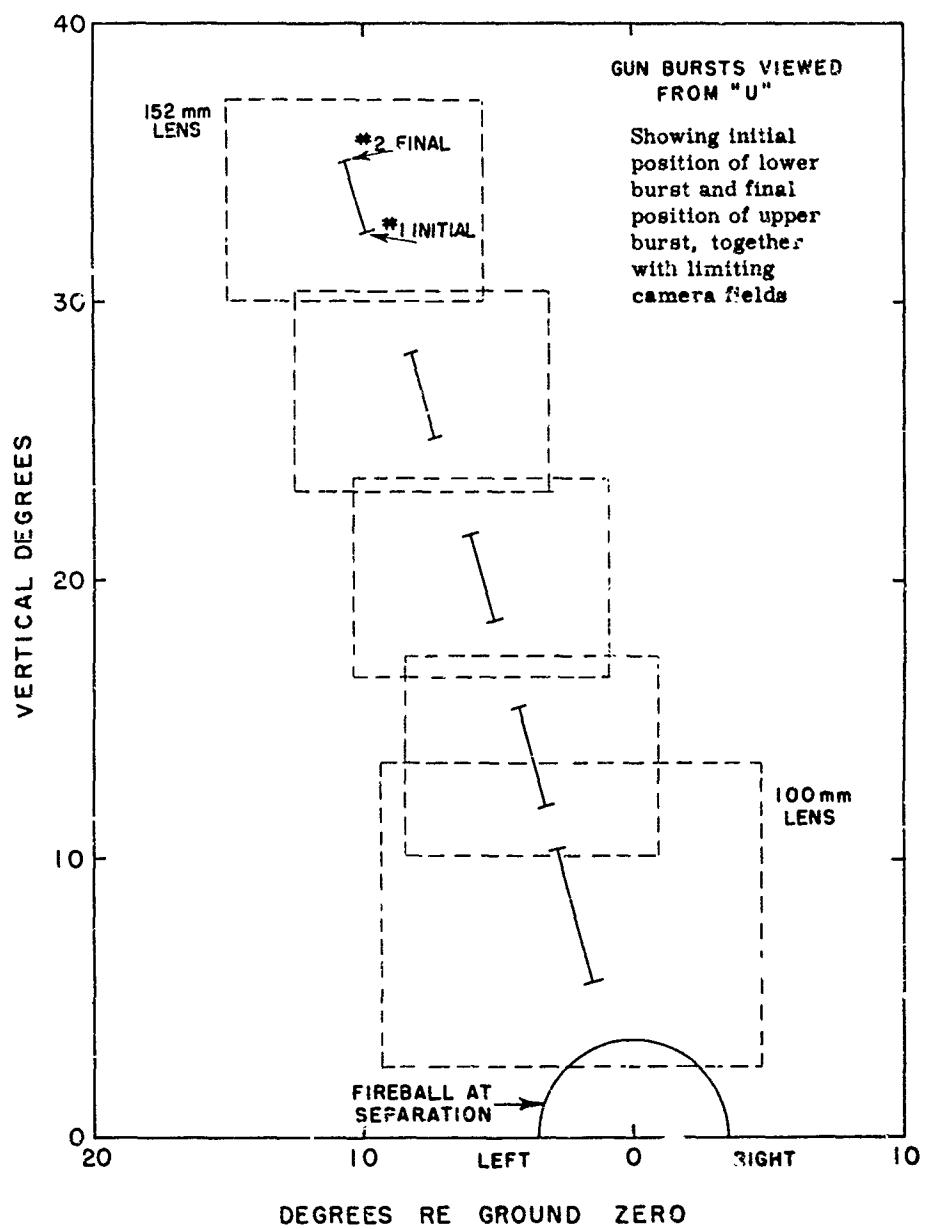


Fig. 8.2—Camera fields of view, gun-burst photography.

CHAPTER 9

**PROJECT 6.4a: WATER-WAVE PHOTOGRAPHY**

Because of the high energy release anticipated from Mike shot, a water wave was expected to result from the detonation. In order to study the passage and dimensions of the wave, Group J-10 of LASL installed poles, rafts, and barrels at varying water depths and distances from Ground Zero. Eastman 16-mm Cine Special cameras, driven by governor-controlled motors, were aimed at these markers from four separate stations (Stations 303, 305, 302, and 307) and were set to run at 12 frames/sec, allowing a total running time of about 10 min. This long running time was necessary because of the uncertainty in time of arrival of the water wave at the different stations and of the exact nature of the phenomena. The cameras were shielded against fall-out radiation by lead boxes as described in Chap. 3.

Three of the cameras recorded the wave motion. The mirror for the fourth camera (Station 303) was destroyed by the blast, and the film shows nothing of interest. Two of the cameras showed a slight change in water level and a disturbance of the barrels. The third showed no disturbance.

CHAPTER 10

**PROJECT 6.14: ROCKET PHOTOGRAPHY**

For King Shot the Naval Ordnance Laboratory (NOL) set up a fan-shaped array of smoke rockets on the shot island, so positioned that the fireball would appear in front of the rocket trails.

Three 35-mm Mitchell cameras running at approximately 100 frames/sec and equipped with 2-cycle velocity markers were operated from Station 308 on Rojoa. Two of these cameras operated satisfactorily, one giving an excellent record of hooks in the trails. The third camera did not run owing to damage caused by the heavy rains previous to shot day. Original negatives were turned over to NOL for analysis.

Space reference markers, which had been requested by NOL, were not installed because the high level of radioactivity at the photostations following Mike shot severely limited the number of man-hours that could be spent on this project.

CHAPTER 11

## PROJECT 10.1: TELEVISION AND WORLD TIME

Two Eastman Cine Special cameras mounted on fixed pedestals recorded the television monitor screen on the USS Estes from M-1 hr to Mike zero, taking two pictures per second from M-60 min to M-2 min. then eight per second until the explosion destroyed the transmitter in the zero station. Figure 11.1 shows the television monitor panel and a typical film record of the television screen.

The world-time rack was installed in the control room aboard the USS Estes for Mike shot, Fig. 11.2, and in the Elmer Control Point (CP) for King shot. This rack was equipped with a short-wave receiver for picking up WWV time signals and contained two clock panels, one indicating the hour, minute, and second and the other indicating seconds and hundredths of seconds. These clocks were each photographed by an EG&G scope camera. A Blue Box caused a flash tube to discharge at shot time and record images of the clock faces. In order to calibrate the clocks, pictures were taken before and after the shot, the flash discharge in these cases being controlled by WWV. The necessary correction factors were determined by means of these calibration pictures.

Both cameras operated satisfactorily on Mike shot. The records are shown in Fig. 11.3, the middle image being the shot picture in both cases. The corrected clock reading is 07:14:59.225. However, owing to a power failure aboard ship at M-40 min, the operation of the clock driving circuits was unstable, and it is thought that the world-time reading is uncertain by  $\pm 0.2$  sec.

The determination for King shot was unsuccessful because the Blue Box did not trigger. A manually operated stop watch shows the burst to have occurred within 2 sec of target time (11:30).

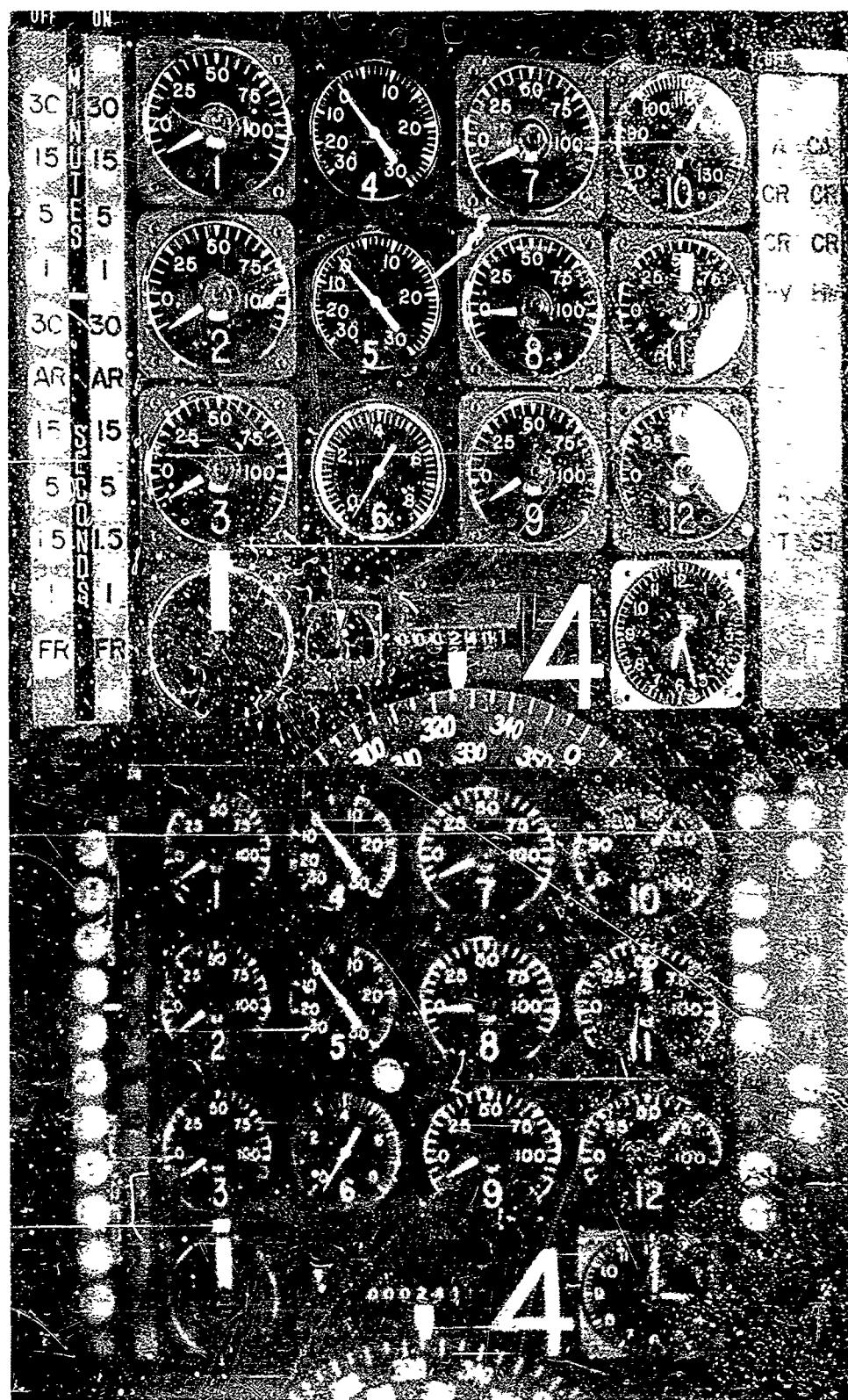


Fig. 11.1—Data monitoring panel with television monitoring record, Mike shot.

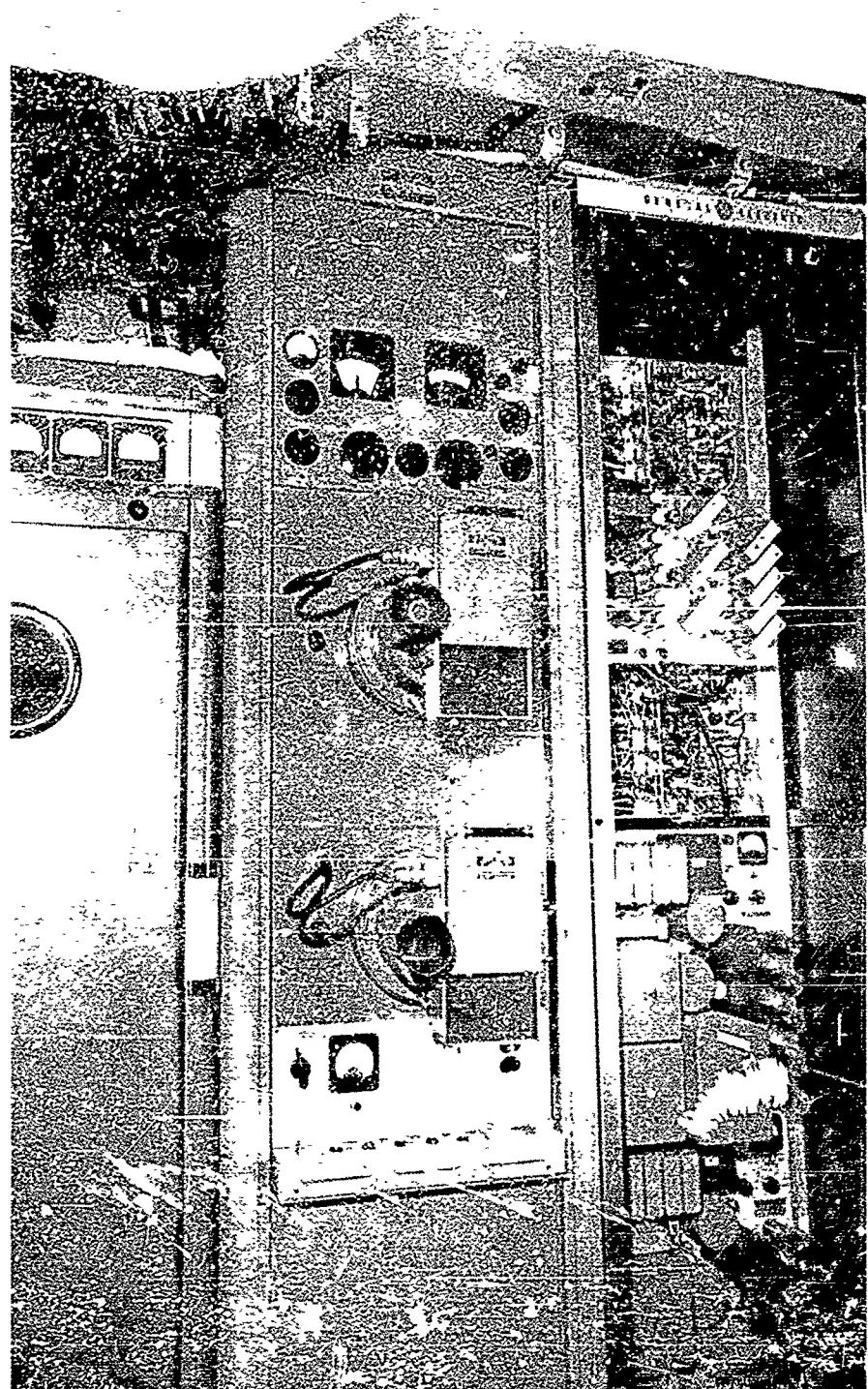


Fig. 11.2—World-time photography installation.

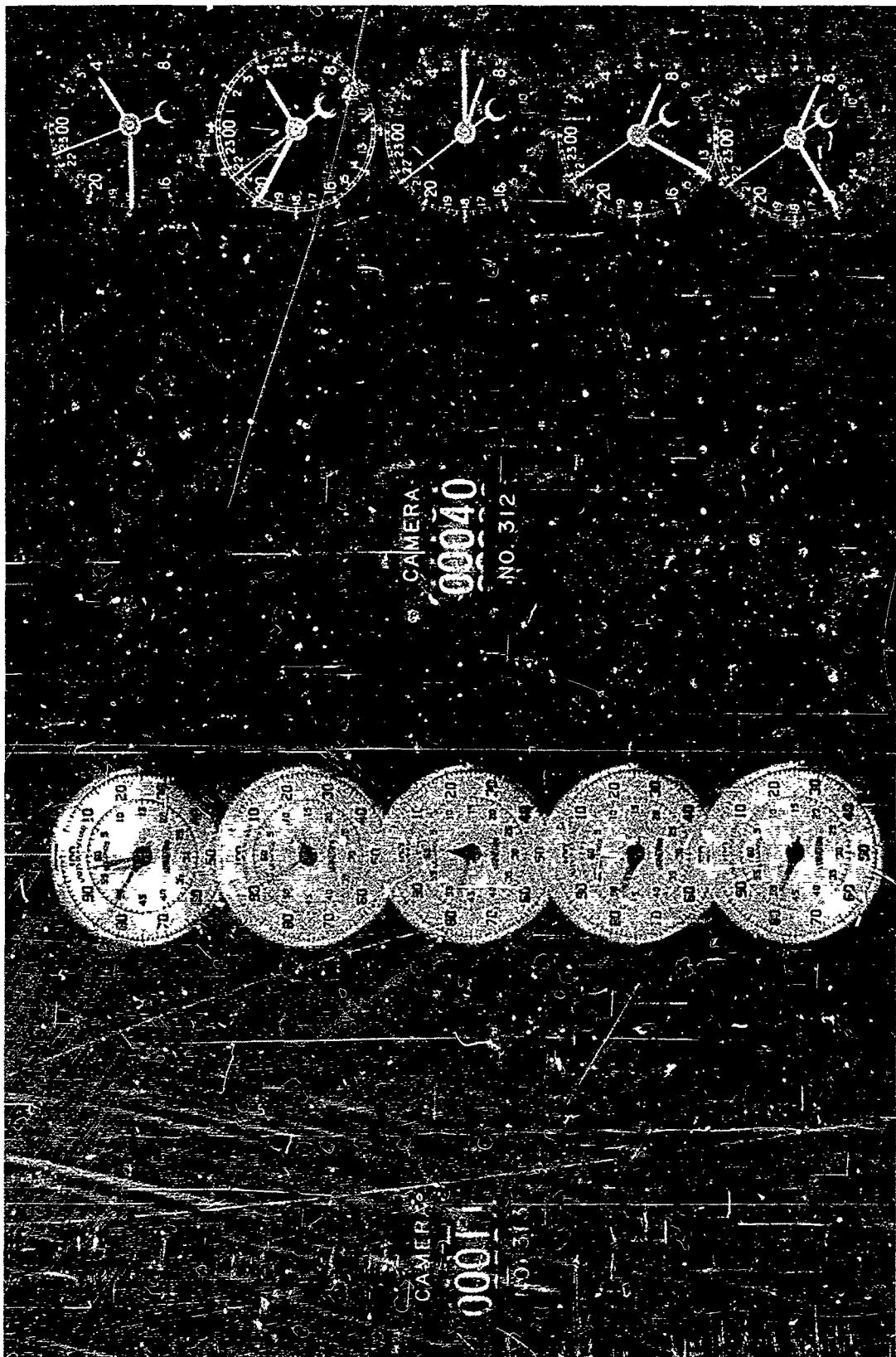


Fig. 11.3—World-time records, Mike shot.

## CHAPTER 12

# MISCELLANEOUS

### 12.1 GMX-9 MODEL 7 CAMERA

One of these ultra high speed cameras was used on Mike shot and two on King shot. The second King shot camera was loaded with Eastman Color Negative film in an effort to record very high speed photographs of the fireball in color. The cameras were run in series with a Heiland recorder which traced the speed of camera rotation on a strip of tape. Markers at two different frequencies (10 and 200 cycles) were employed as a check on each other and to guarantee a time scale for the films.

The GMX-9 Model 7 camera is an experimental high-speed camera developed at LASL. The image formed by the primary optical system is formed on the surface of a rotating mirror which sweeps the light across a second bank of lenses, each one of which forms an image for one position of the mirror. A blast-wave capping shutter is used to prevent recycling or multiple exposures. The speed of the mirror can be adjusted so as to attain a maximum picture-taking rate of 90,000 frames/sec.

Satisfactory records were obtained from the GMX camera on Mike shot only. A sample frame from this record is presented in Fig. 12.1.

### 12.2 IMAGE-CONVERTER CAMERA

One experimental image-converter camera was set up in the Elmer tower (Station 301) for Mike shot. In this arrangement the image-converter tube acts as a photographic shutter. The image-converter tube takes an optical image, converts it to an electron image, and, by means of phosphors, reconverts the image into an optical image which can be photographed. During the conversion process the intensity of the original image can be increased several times. This is a great advantage over standard optical systems, where only a reduction in light intensity is possible as the image passes through various lenses. With this system it is also possible to attain extremely short exposure times by placing a positive potential on the anode of the tube for the desired time. This causes the electrons to flow toward the anode, with consequent conversion of the electron image to an optical image.

The operation of this type of camera is described in detail elsewhere.<sup>1</sup> In this installation the tube and associated power supply were operated using a 72-in.-focal-length Newtonian type telescope lens as the field lens. This was mounted (see Fig. 12.2) beside the tube and camera assembly, with a mirror arranged so as to direct the Newtonian image to the image-converter tube. Because of the extremely high light levels expected from a blast the size of Mike, it was necessary to use several types of shutters to guarantee that no fogging of the film resulted after the picture had been exposed. One of these was a Rapatronic type 1- $\mu$ sec shutter which was placed between the camera and the tube. A second setup used a wire positioned between two

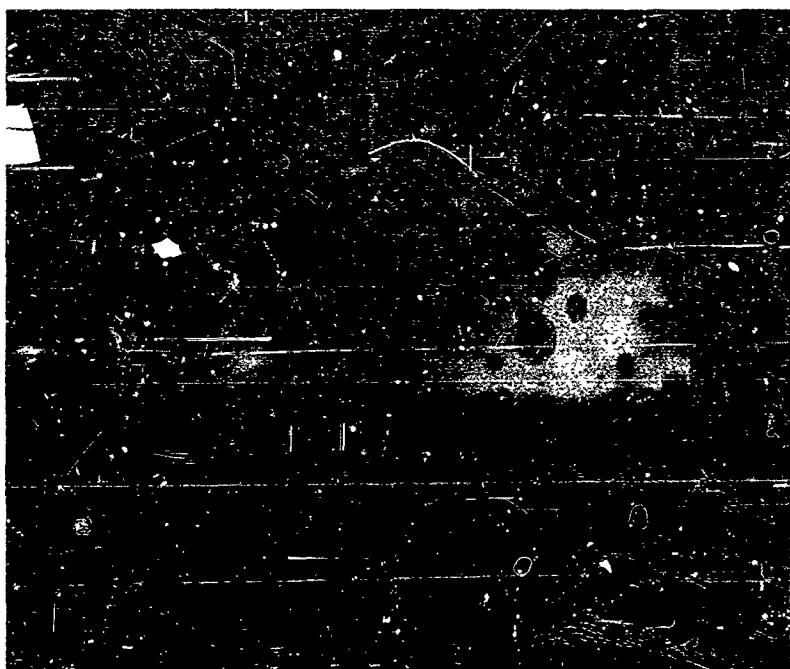


Fig. 12.1—GMX-camera record, Mike shot.

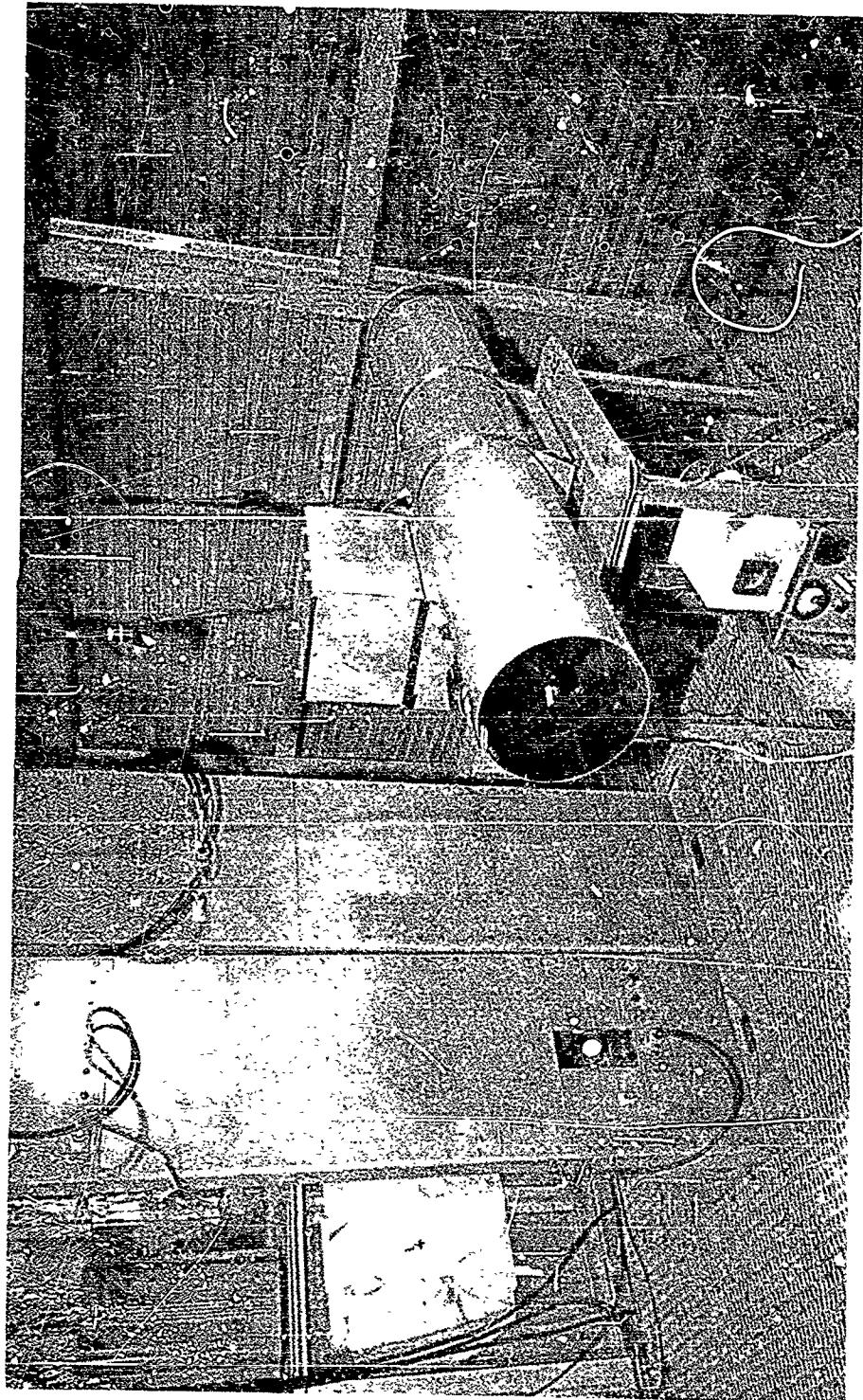
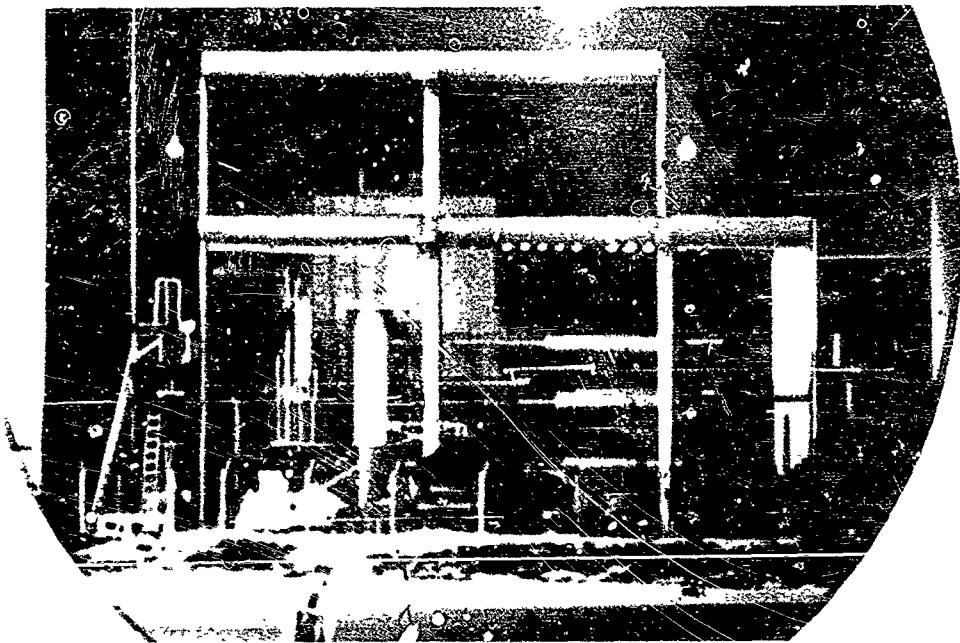
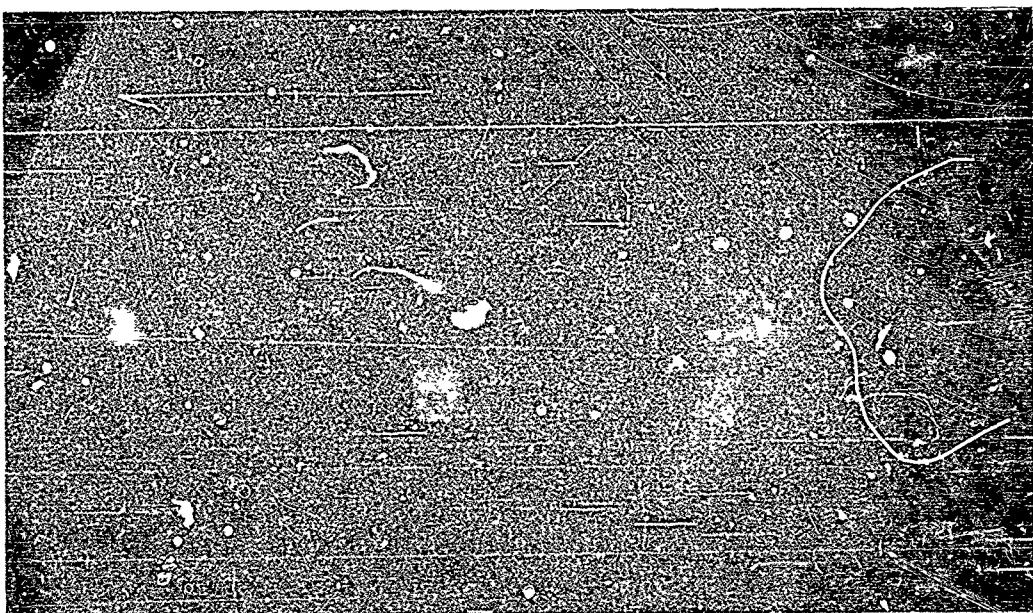


Fig. 12.2—Image-converter-camera installation.



(a)



(b)

Fig. 12.3—Teletronic image, Mike shot. (a) Prezero. (b) Postzero.

SECRET - RESTRICTED DATA

pieces of glass. An electrical pulse through the wire caused the glass to break and craze, thus effectively blocking the passage of light through the glass. A mechanical shutter was also placed next to the lens of the scope camera. The first two, combined with the natural shutter effect of the image-converter tube, were required to assure that the light was cut off immediately after the desired exposure. The third, a slower mechanical type, operated to be sure that no leaking of light occurred between exposure time and time of recovery of the film.

Because of the uncertainty in the expected light level, it was decided to use an ND-2 filter in front of the lens to make sure the bomb light would not burn an image into the tube. Unfortunately, this guess resulted in too heavy filtering, so that no image appeared on the film. Operation of the equipment components was completely satisfactory, however, and the heavy filtering was believed to be the only reason why no picture was obtained.

### 12.3 TELETRONIC CAMERA

An experimental camera similar in operation to the Rapatronic and equipped with a 160-in.-focal-length Cassegrainian type telescope lens was installed in the bunker at Station 300 for use on Mike shot. Similar cameras had been successfully employed on previous operations to record detail of action in the cab at the instant of detonation. A special 1- $\mu$ sec shutter, used in place of the conventional Rapatronic shutter, was required because of the extremely high speed with which such early visible reactions take place. Camera operation was completely satisfactory. The resulting photograph, taken at approximately 5  $\mu$ sec after zero, appears in Fig. 12.3.

Because of the uncertainty in burst time and location for King shot, no attempt was made to record data with the Teletronic camera.

### REFERENCE

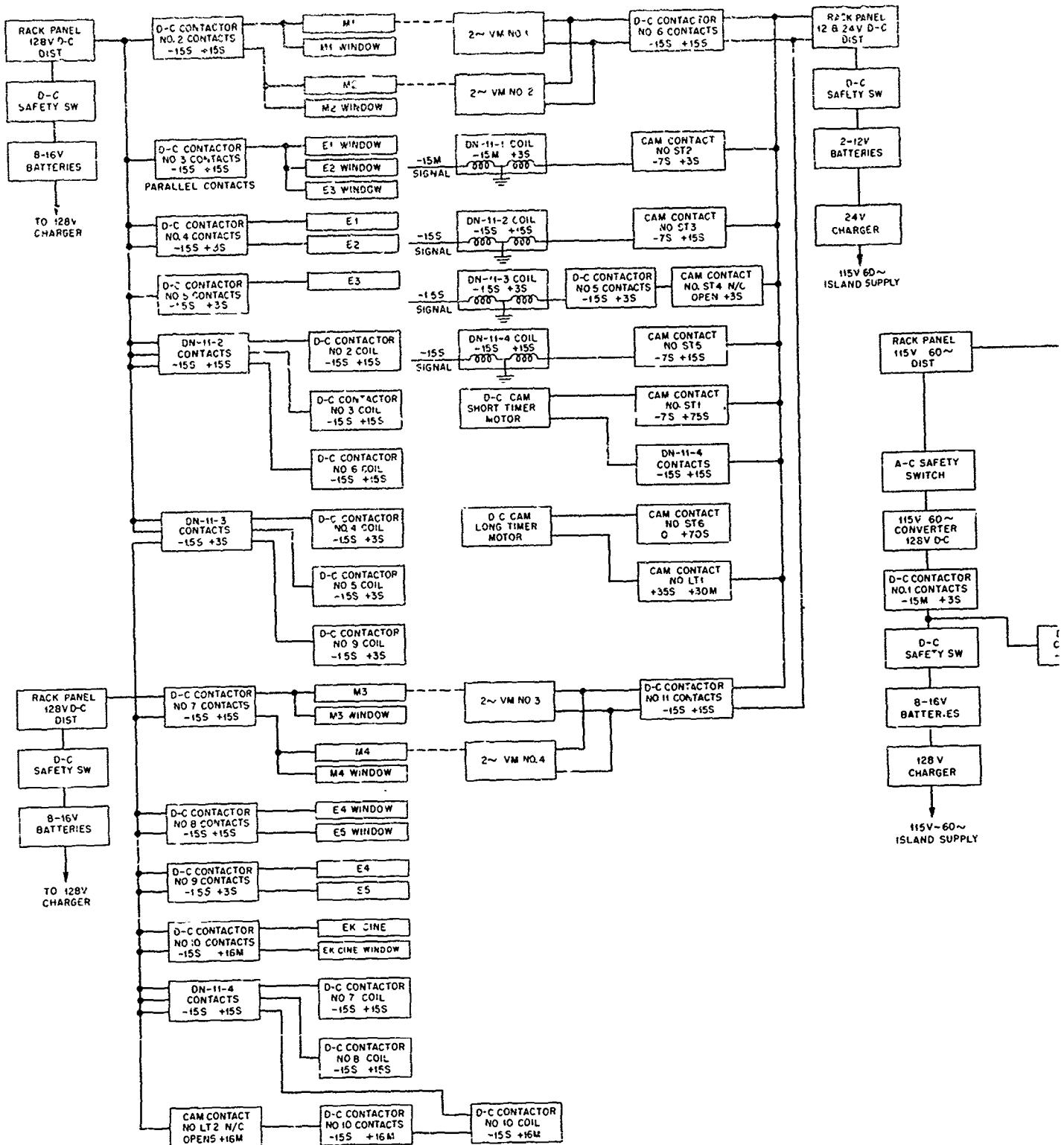
1. NavOrd Report 1811, High Speed Photography with the 1P25A Image Converter Tube, Naval Ordnance Laboratory, White Oak, Md., Nov. 23, 1951.

**APPENDIX A**

**BLOCK DIAGRAMS OF PHOTOSTATIONS**

59-60

**SECRET - RESTRICTED DATA**



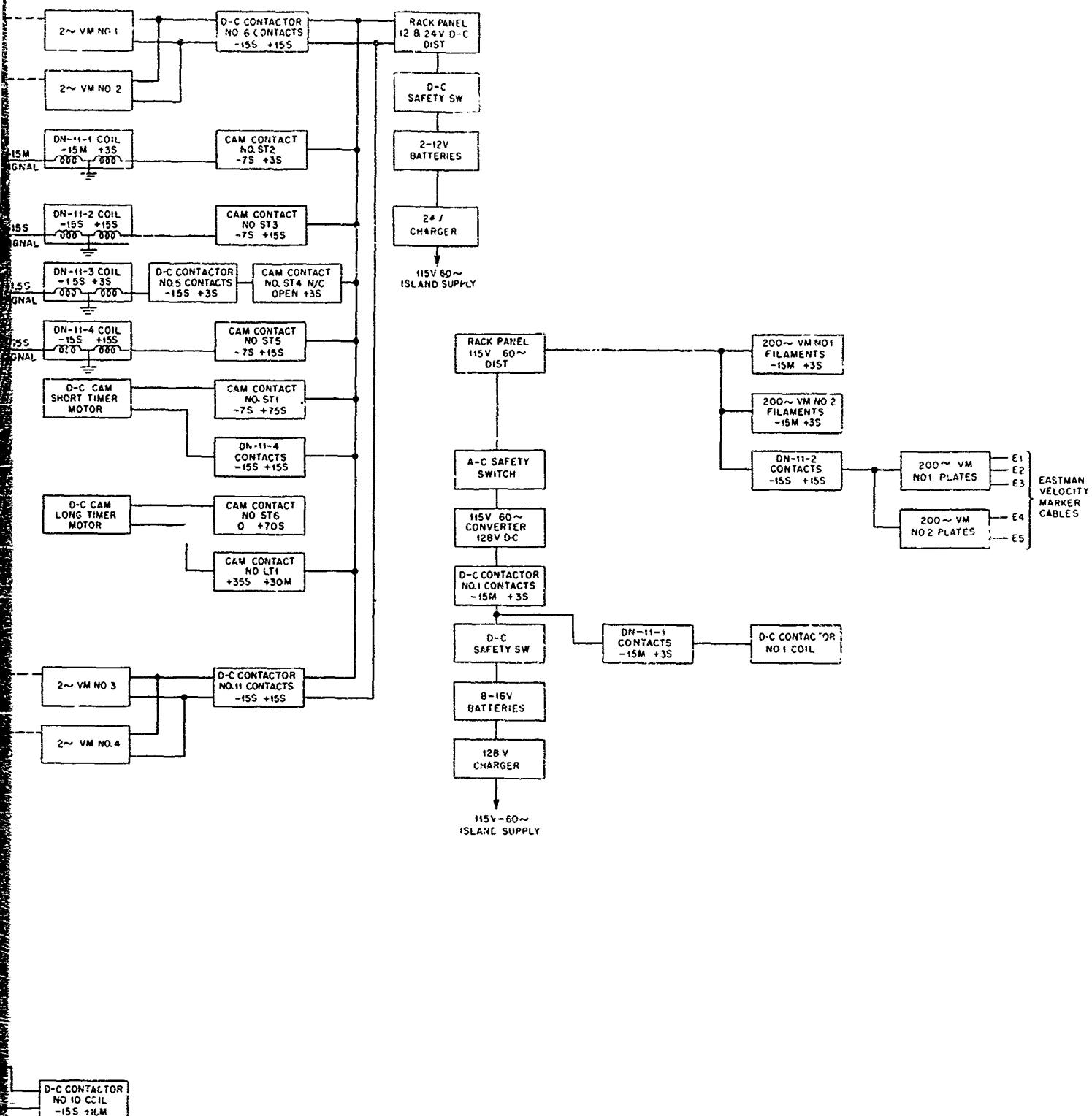


Fig. A.1—Photograp. installation, Janet, Mike slot

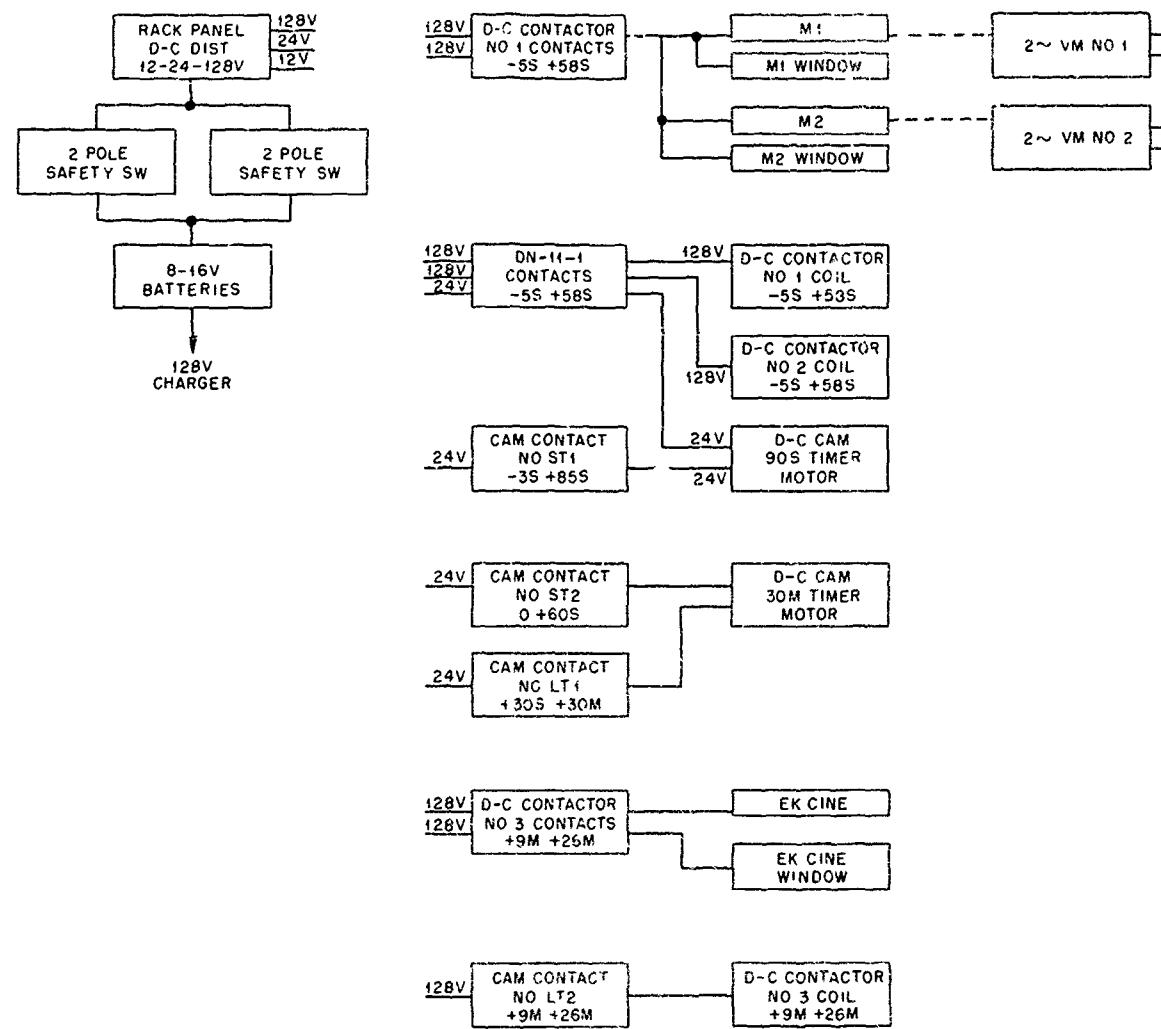


Fig. A.2—Photographic installation, Yvonne, Mike shot.

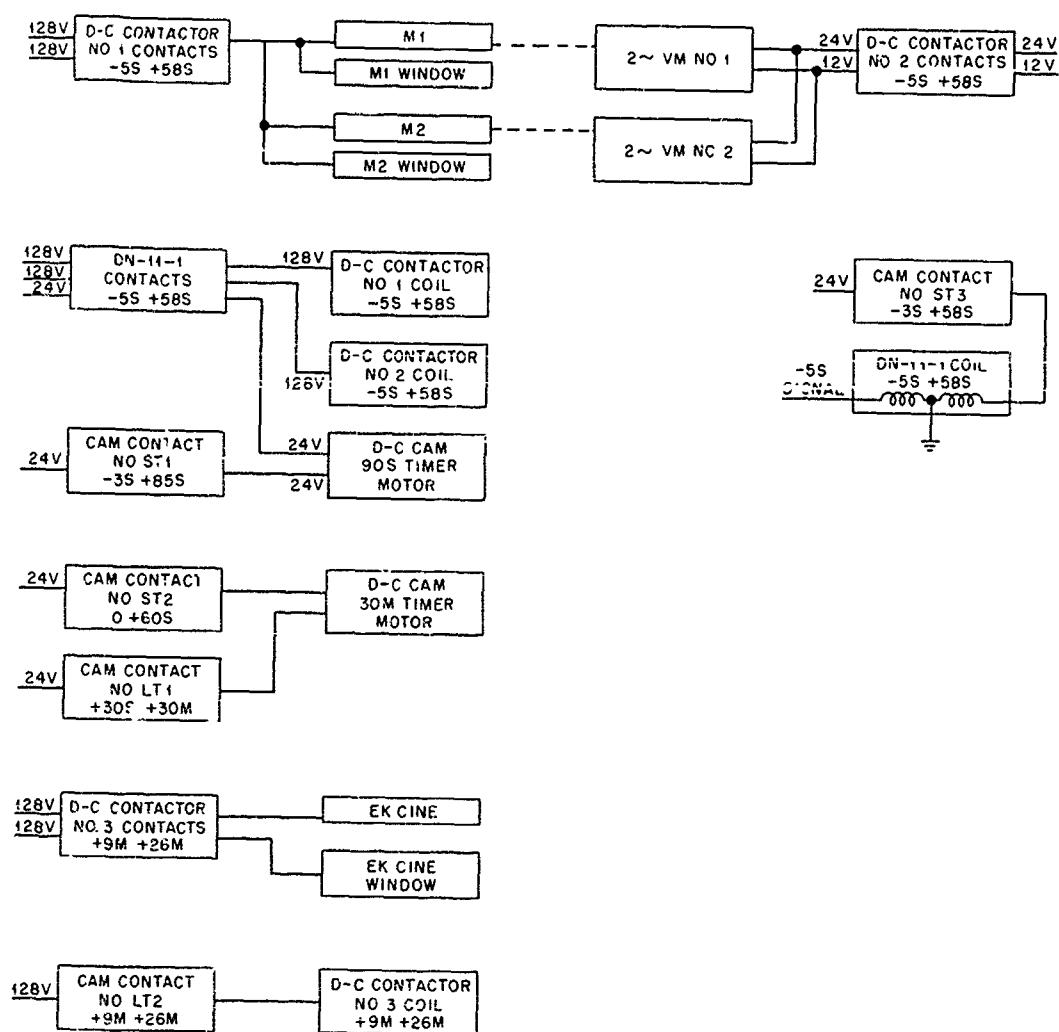


Fig. A.2—Photographic installation, Yvonne, Mike shot.

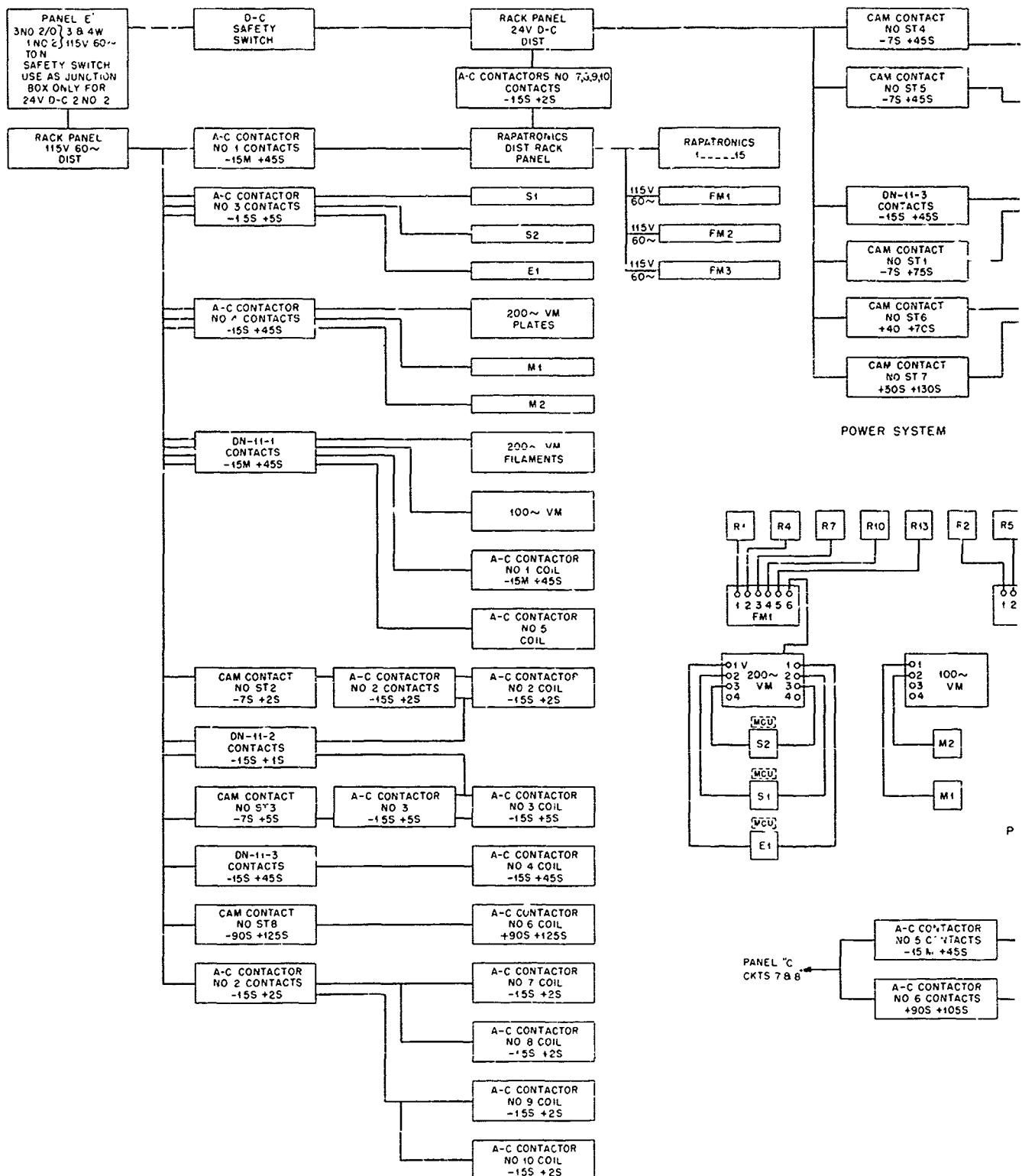


Fig. A.3—Photographic installation, Elmer tower Mike and King shots.

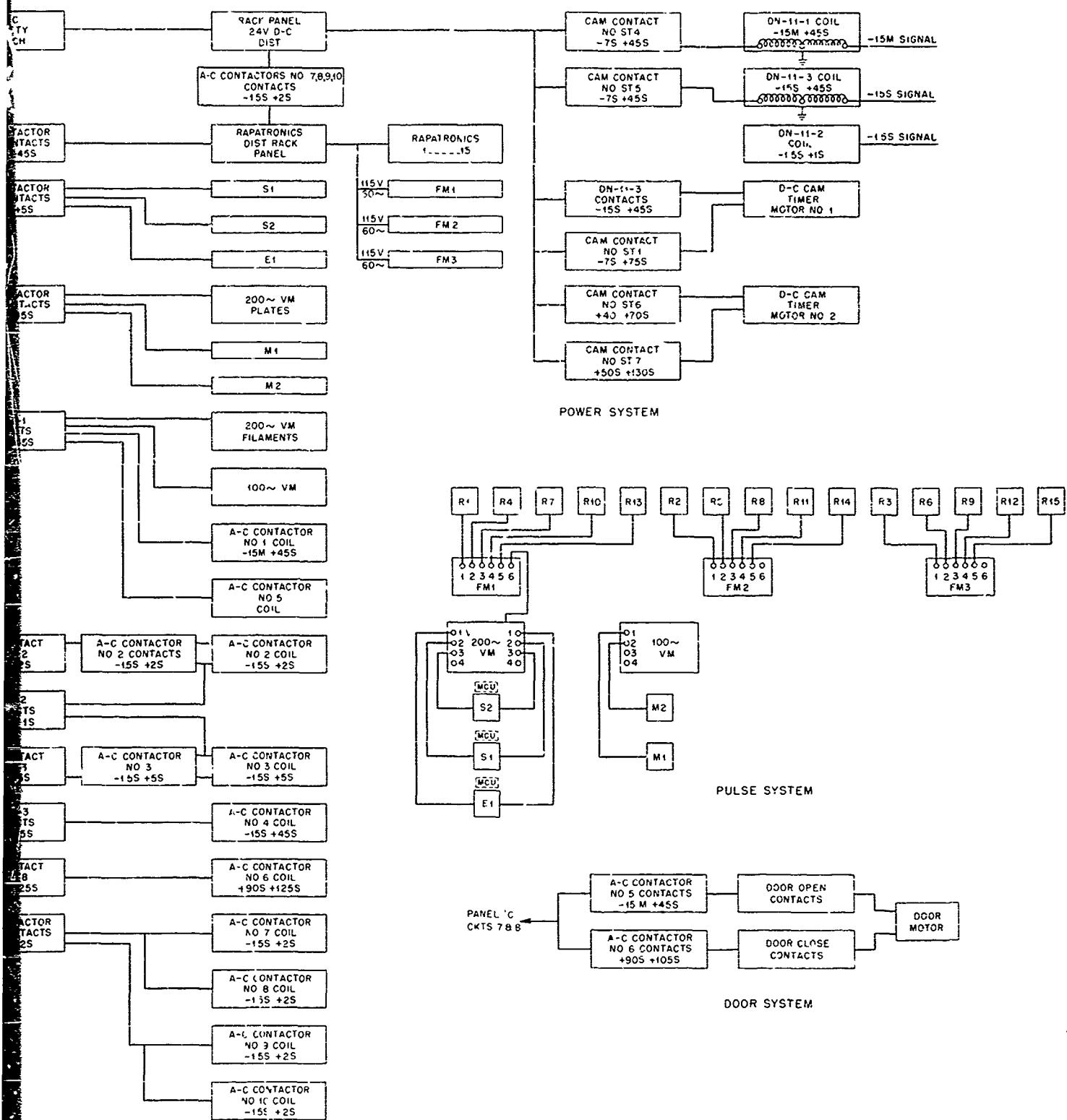


Fig. A.3—Photographic installation, Elmer tower, Mike and King shots.

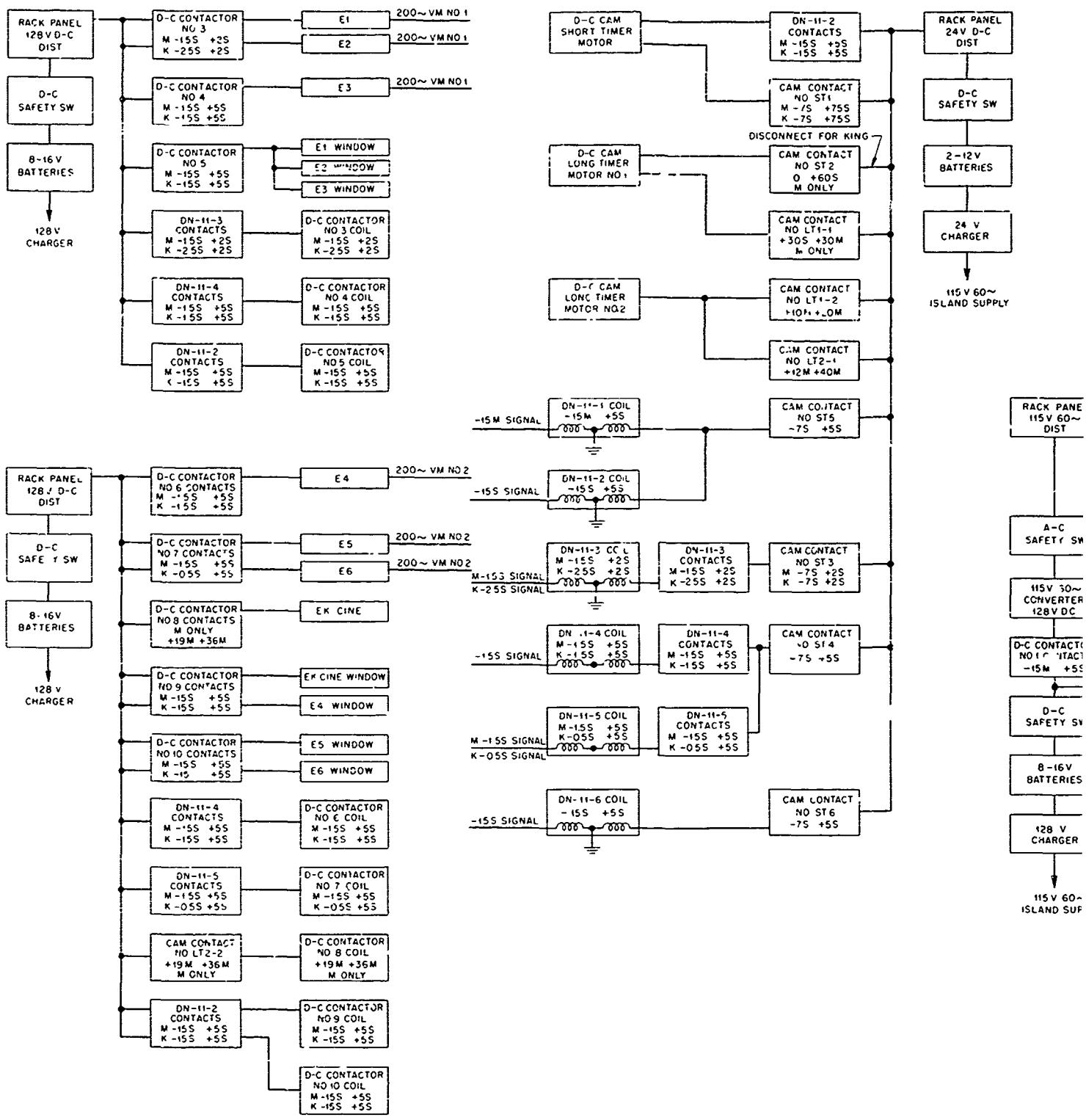


Fig. A.4—Photographic installation, Elmer ground, Mike and King shots.

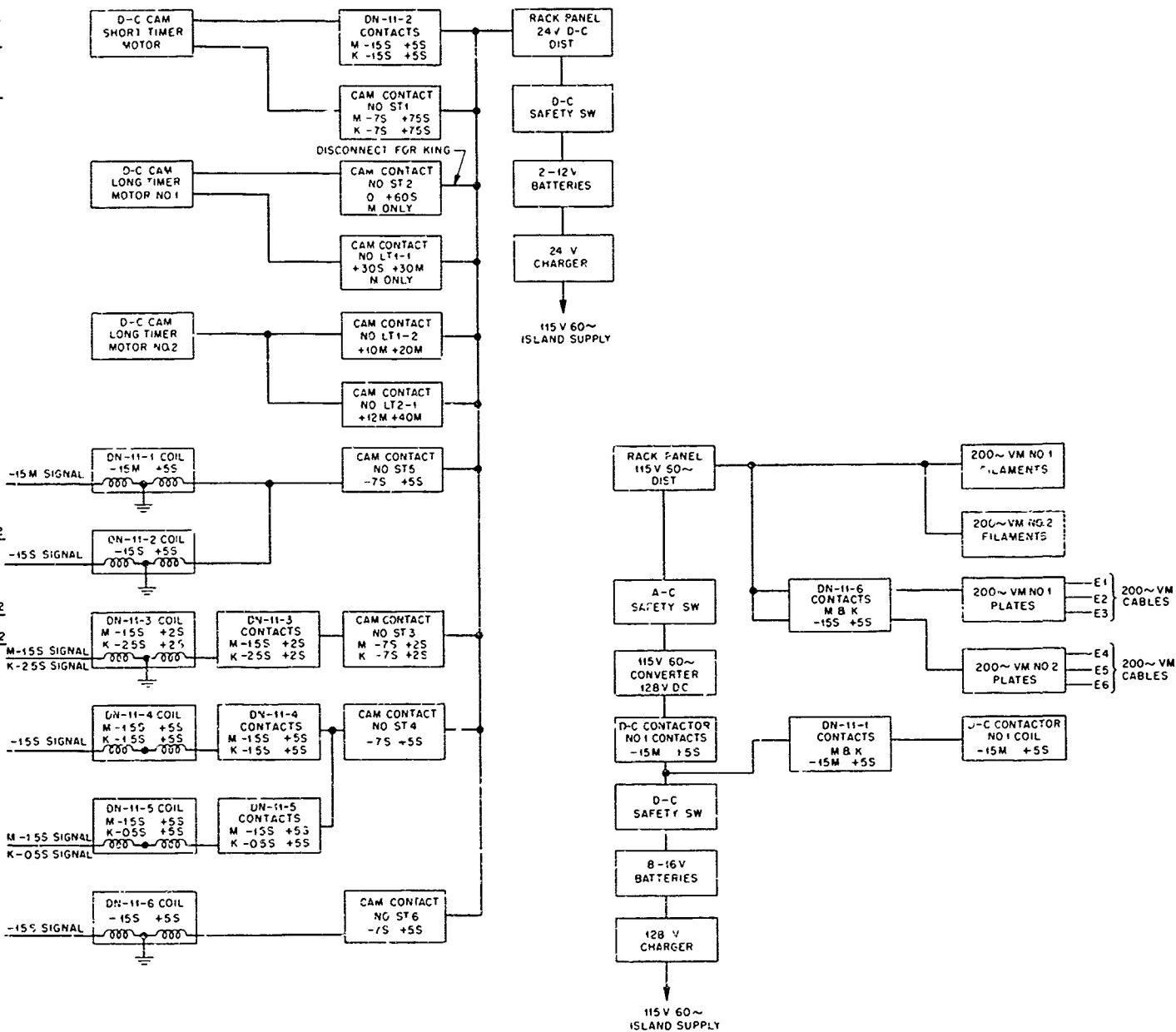


Fig. A.4—Photographic installation, Elmer ground, Mike and King shots.

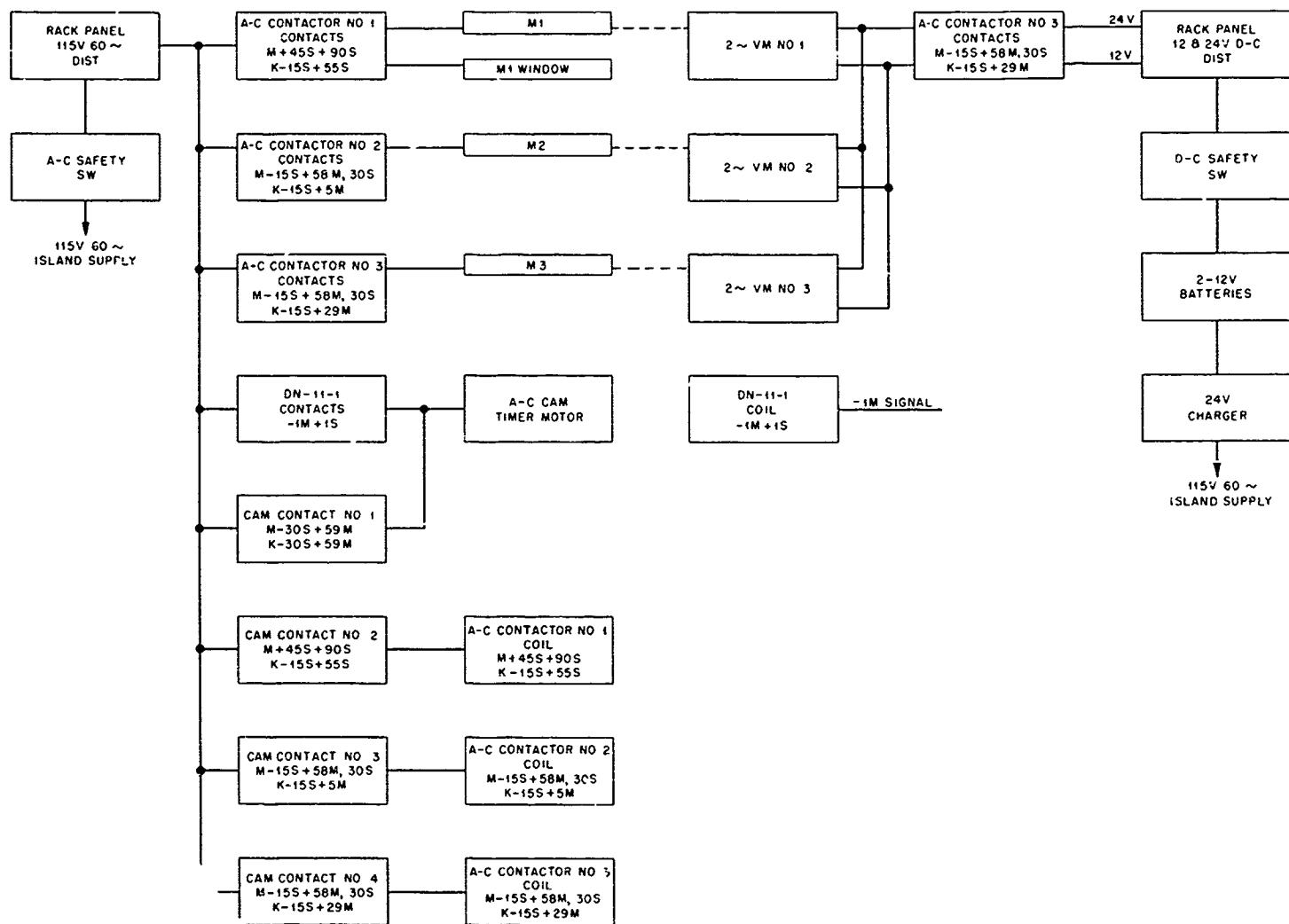


Fig. A.5—Photographic installation, Elmer CP, Mike and King shots.

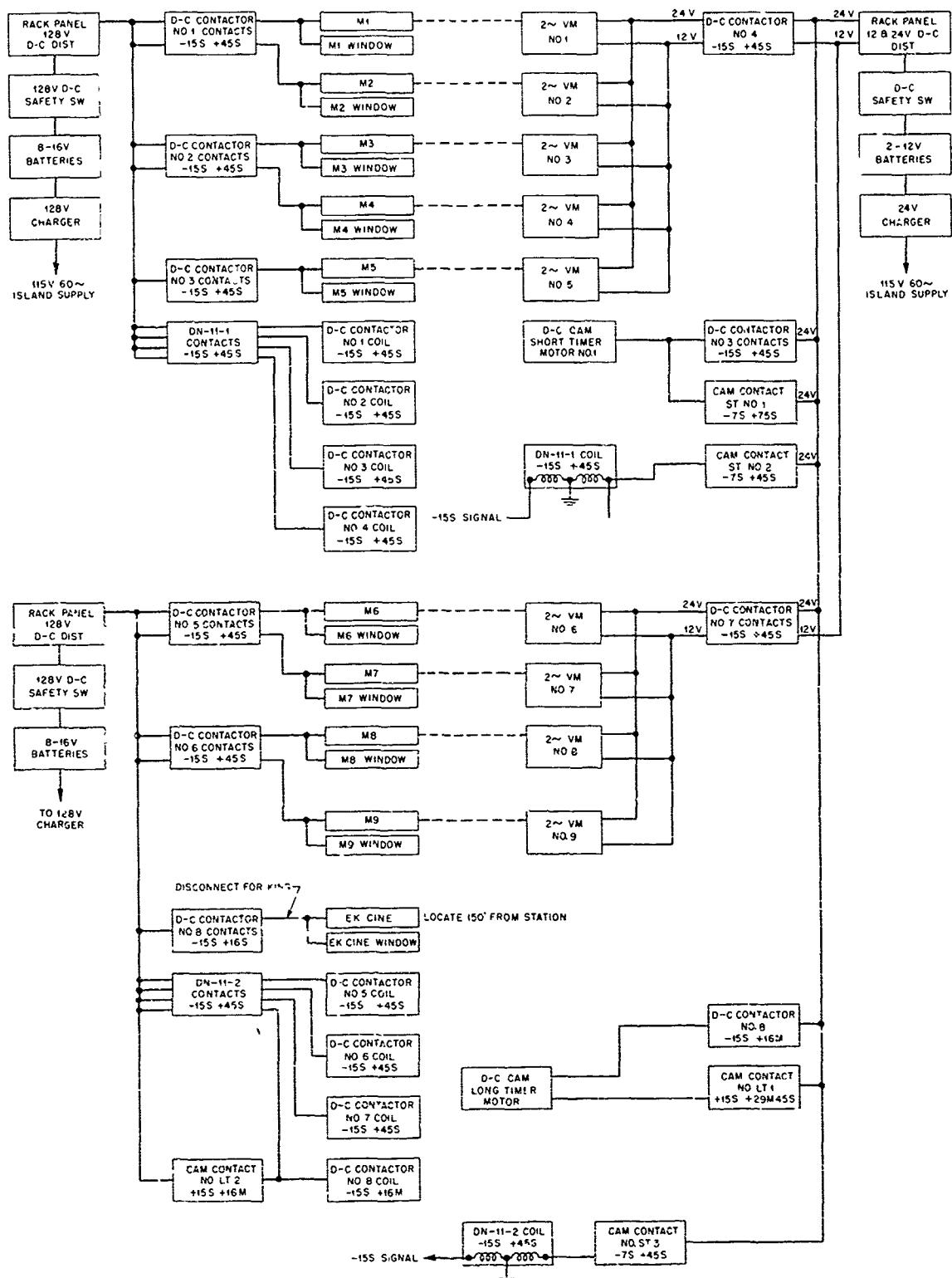


Fig. A.6—Photographic installation, Ursula, Mike and King shots.

APPENDIX B

## **FILM COMPOSITION AND DISPOSITION**

The various films from this operation were assembled by subject matter into reels up to 400 ft in length. Composition of these reels is shown in detail in Tables B.1 and B.2. Projection prints were made from all reels, and copies were issued as follows: three copies, J-Division, LASI; two copies, Chief, Armed Forces Special Weapons Project, Washington, D. C.; two copies, EG&G, Boston; one copy, EG&G, Las Vegas. One additional copy of the King rocket reel was also sent to NOL, Washington, D. C.

Fine-grain master positive copies and prints of the Ivy records were sent to the Air Force Lookout Mountain Laboratory to make tinted Kodachrome master footage for the Ivy documentary.

Table B.1—MIKE RELEASE-PRINT ASSEMBLIES

Reel	Perforation No.	Nominal frames/sec	Focal length of lens, mm	Camera station	Distance from zero, miles	Direction
Fireball	16,125	100	152	EE-301	22	SE
	16,109	3000	102	J-303	3.7	E
	16,108	3000	102	J-303	3.7	E
	16,107	3000	102	J-303	3.7	E
	16,111	3000	25	J-303	3.7	E
	16,110	3000	25	J-303	3.7	E
	16,103	3000	102	EE-302	22	SE
	16,101	3000	102	EE-302	22	SE
	16,102	3000	102	EE-302	22	SE
	16,104	1000	102	EE-302	22	SE
	16,112	1000	102	Ship	~30	
Mass motion	16,171	70	100	U-306	10.1	E
	16,172	70	152	U-306	10.1	E
	16,173	70	152	U-306	10.1	E
	16,174	70	152	U-306	10.1	E
	16,175	70	152	U-306	10.1	E
	16,176	70	75	J-303	3.7	E
	16,178	70	75	J-303	3.7	E
	16,179	70	75	J-303	3.7	E
	16,180	70	152	U-306	10.1	E
	16,181	70	152	U-306	10.1	E
	16,182	70	152	U-306	10.1	E
	16,184	70	152	Y-307	13.2	SE
	16,125	100	152	EE-301	22	SE
	16,119	1/2	18.5	EE-308	22	SE
Timing record, television	16,117	2-8	15	Ship		
	16,118	2-8	15	Ship		
Water-wave motion	16,114	12	25	U-306	10.1	E
	16,115	12	25	Y-307	13.2	E
	16,116	12	25	EE-308	22	SE

Table B.2—KING RELEASE-PRINT ASSEMBLIES

Reel	Perforation No.	Nominal frames/sec	Focal length of lens, mm	Camera station	Distance from zero, miles	Direction
Fireball	16,201	3000	102	EE-302	10.4	S
	16,204	2000	102	EE-302	10.4	S
	16,205	3000	102	EE-302	10.4	S
Mass motion	16,276	100	152	U-303	4	N
	16,277	100	152	U-306	4	N
	16,278	100	152	U-306	4	N
	16,279	100	152	U-306	4	N
	16,294	600	102	Y-307	1.5	S
Shock velocity (rockets)	16,293	100	102	U-306	4	N
	16,291	100	35	U-306	4	N

APPENDIX C

**METEOROLOGICAL DATA**

Table C.1—METEOROLOGICAL CONDITIONS, OPERATION IVY

Shot	Date	Local time	Pressure, in. Hg	Temperature, °C		Relative humidity, %	Air density, g/liter
				Dry bulb	Wet bulb		
Mike	11/1/52	0714:59.4 ± 0.2 sec	29.79	29.4	24.2	64	1.118*
King	11/16/52	1130:00 ± 2 sec	29.84	29.4	26.6	80	1.109†

\*At center of gravity of fireball.

†At burst height.

**APPENDIX D**

**CAMERA DATA SHEETS**

71-72

**SECRET - RESTRICTED DATA**

EDGERTON, GERMESHAUSEN & GRIER, INC.

CAMERA DATA SHEET  
TEST ~~xx~~ DATE 11/16/58 STA. 3/21

PARRY TOWER

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

## CAMERA DATA SHEET

TEST ~~Ivy-Mike~~ DATE 11/1/52 STA. 501

PARRY TOWER

PERF. CODE	EMULS.	FILTERS	APER.	AIMING		POWER	TIMING		MARKERS, SERIALS			RACK POS.	CAM NO.		
				ND	COLOR		SET.	HORIZ.	VERT.	ON	OFF	FM.			
16,141	HRNS	0 0	11	0-00	1-00	115AC		-15M	+45S	8	NONE	NONE		R-39	
42	MF	" "	"	"	"			2400	-15S	21	"	"		4	
43	"	" "	"	"	"			"	"	3	"	"		9	
44	"	" "	"	"	"			"	"	21	"	"		15	
45	"	" "	"	"	"			"	"	3	"	"		19	
46	HRNS	" 0	"	"	"			"	"	8	"	"		29	
47	"	" "	"	"	"			"	"	3	"	"		2	
48	TRIX	" "	"	"	"			"	"	8	"	"		23	
49	"	" 4	"	"	"			"	"	3	"	"		8	
50	"	" "	"	"	"			"	"	21	"	"		10	
51	"	" "	"	"	"			"	"	21	"	"		14	
52	"	" "	"	"	"			"	"	3	"	"		24	
20	FCN	2 0	56	0.00	5-30	85AC	0/30	-15S	SELF+5	8	200-109	109		E-6	
99	MF	0 0	26.0	0-00	0-00	115AC				3					
96	809	- -	-							3	200-105	200-105		HE-104	
28	S-XX	MF	12	-	0-00	0-00	120AC		-15S	SELF+5	8	200-109	109		GR-2
29	FCN	" "	-	"	"	"	"	"	"	8	"	109	109		GR-3
25	MF	1 12	56 10 <sup>0</sup>	0-00	2-30	115AC		-15S	+45S	NONE	100-146	NONE		44-11	
21	FCN	3 -	11 15 <sup>0</sup>	"	14-00	"		"	"	8	"	"	NONE	EH-6	
95	FCN	- -	30	0-00	0-00	-		-15S	80	--	8404	NONE	-	HE-1	
97	TRIX	2 0		0-00	0-00	115AC		-15S	8	NONE	-			EG-1	
										BB-4					

## EDGERTON, GERMESHAUSEN & GRIER, INC.

## CAMERA DATA SHEET

TEST IV-Y-M DATE 11-1-52 STA. 302 & 308  
7-14-59.4 ± 0.2

PARRY GND.

## EDGERTON, GERMESHAUSEN & GRIER, INC.

## **CAMERA DATA SHEET**

Parry Gnd.

TEST 11VY-M DATE 11-1-52 STA. 302 & 308  
7-14-59.4 ± 0.2

PERF. CODE	EMULS.	FILTERS	APER. SET.	AIMING		POWER	TIMING		MARKERS, SERIALS			RACK POS.	CAM NO.	
				ND	COLOR		HORIZ.	VERT.	ON	OFF	FM.	VEL.		
16,101	MF	0	12	4	0-00	1-10	120 DC	20/16	-1.5 S	SELF	+12	NONE	200-102	NONE B E-20
02	"	0	"	8	"	"	-	"	"	"	"	"	"	C E-15
03	"	1	"	5.6	"	"	"	"	"	"	"	"	"	D E-12
04	"	0	"	2.7	"	"	+20/20	"	"	+5	"	-104	"	E E-18
05	"	1	"	4	"	2-00	-	"	-	"	"	"	"	F E-24
06	"	2	"	4	"	5-30	-	"	"	"	"	"	"	G E-10
16	MF	0	0	1.9 OPEN	0-00	0-00	"	"	+21m	+33m	NONE	NONE	NONE	A ECS-3
85	PLUS X	0	0	2.3 170°	0-00	32-00	115 AC	+45S	+90S	NONE	2-18	NONE	A ML-18	
19	MF	0	12	4 20°	0-00	7-24	70 V AC	-15S	+60m	-	NONE	"	"	C ML-9
20	ECN	0	NONE	11 20°	0-00	7-24	-	"	-	"	"	"	"	B ML-10

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

CAMERA DATA SHEET  
TEST IV-M DATE 1/1/52 STA. 303

## ENGBEI

REMARKS & NOTES DESIGN W/M <sup>2</sup>	PURPOSE	~FR./SEG.	CAMERA			TIME OPER.	LENS	
			NO.	SERIAL	MAG.		FOC. LGH.	SERIAL
$8 \times 10^4$	LOW ORDER	3000	E-16	1513		0-18	102	RY 501
$3 \times 10^5$	"	"	E-9	1493		"	"	ET 506
$1.5 \times 10^7$	EARLY	"	E-25	1520		"	"	ET 201
$9 \times 10^4$	High Order	"	E-27	1514		0-45	25	RY 189
KNOCKED OFF PEDESTAL	$3 \times 10^5$	"	E-11	1521		"	"	RY 175
200	WATER WAVES	12	ECS-7	—		0-15m	25	RC 382
2 ~ = 1.96 cps								
VIEWS - MORTAR STA.								
Ms. 620.01								
1.98	620.02	"	BH-2	1093		0-45S	75	UF 5725
1.96	620.03	"	BH-3	1095		"	"	UF 5833
1.96	620.04	"	BH-4	1099		"	"	UF 5653
			BH-5	1096		"	"	UF 5701R
Mirrors were blown off of all camera shelters. Useful record censes, at +7sec.								

**SECRET – RESTRICTED DATA**

## EDGERTON, GERMESHAUSEN & GRIER, INC.

## CAMERA DATA SHEET

ENGEBL

TEST Ivy-Mike DATE 11/1/52 STA. 303

PERF. CODE	EMULS.	FILTERS		APER. SET.	AIMING		POWER	TIMING		MARKERS, SERIALS			RACK POS.	CAM NO.	
		ND	COLOR		HORIZ	VERT.		ON	OFF	FM.	VEL.	ZERO			
16,107	MF	0	12	5.6	0-00	2-00	120DC 30/86	-1.5 S	SELF,+3S	NONE	200-106	NONE	F	E-16	
108	"	0	"	11	"	1-10	"	"	"	"	"	-105	"	G	E-9
109	"	2	"	8	"	"	"	"	"	"	"	-105	"	H	E-25
110	"	0	"	5.6	"	5-30	"	"	"	"	"	-106	"	I	E-27
111	"	0	"	11	"	"	"	"	"	"	"	-106	"	J	E-11
16,113	MF	0	0	19 Open	R	0-00	120DC	-15S	+15m	NONE	NONE	NONE	E	ECS-7	
76	MF	1	12	11 15°	19-34R	0-00	120 DC	-15 S	+15 S	NONE	2-7	NONE	D	BH-2	
77	"	1	"	11 15°	22-23R	"	"	"	"	"	2-10	"	C	BH-3	
78	"	1	"	8 15°	28-55R	"	"	"	"	"	2-14	"	B	BH-4	
79	"	1	"	5-6 15°	40-16R	"	"	"	"	"	2-9	"	A	BH-5	

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

## CAMERA DATA SHEET

TEST Ivy-M DATE 11-1-52 STA. 306 & 305

RojoA

EDGERTON, GERMESHAUSEN & GRIER, INC.

## **CAMERA DATA SHEET**

TEST Ivy-Mixedate 11-1-52 STA. 306 & 305

ROJOA

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

## **CAMERA DATA SHEET**

TEST Ivy-M DATE 11-1-52 STA. 307

Runit

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

## **CAMERA DATA SHEET**

TEST Ivy-Mike DATE 11-1-52 STA. 307

RUNIT

## EDGERTON, GERMESHAUSEN & GRIER, INC.

## CAMERA DATA SHEET

TEST Ivy-M DATE 11/1/52 STA. ESTES

ESTES

REMARKS & NOTES	~FR./SEC.	CAMERA			TIME OPER.	LENS	
		NO.	SERIAL	MAG.		FOC. LGH.	SERIAL
Design Purpose $W/m^2$							
$1.5 \times 10^5$ Fireball	1000	F-26	1518			102	ET 234
" "	100	F-7	1443			63	ET 1229
Processed &							
analyzed 1/1/52							
changed to 8/sec, f 2.7AT-2 min.	T-V	2	ECS-1		-32 min to 0	15	
" " " " " " T-V	2	ECS-2			" "	"	RC 186
Did not trigger	T-MIN	Single	BM-3			50	
RECORD	"	"	BM-6			"	
Did not trigger	"	"	BM-1			"	
" "			BM-8			"	
$7^h - 14^m - 59.4^s \pm 0.2$	World Time	Single	EGG-			50	
" "	" "	"	EGG-			"	
1 shot/min, various parts of cloud	SPD. GRN.	PT1055	0 to 11 min	127	RA 1274		
" "			112 to +23	"	"		
" "			+23 to +30	"	"		

## EDGERTON, GERMESHAUSEN & GRIER, INC.

## **CAMERA DATA SHEET**

ESTES

TEST Ivy-MIKE DATE 11/15/52 STA. ESTES

PERF. CODE	EMULS.	FILTERS		APER. SET.	AIMING		POWER	TIMING		MARKERS, SERIALS			RACK POS.	CAM NO.
		ND	COLOR		HORIZ.	VERT.		ON	OFF	FM.	VEL.	ZERO		
16,112	ME	0	12	5.6	0-00	1-00	110AC 20/20	-2.5	+2.5	NONE	200-107	NONE	STAB. PLATF.	E-26
16,12.7	MF	0	0	5.6	0-00	1-00	" 30/50	-2	+2	"	"	"	"	E-7
17	BX	NONE	NONE	56/OPEN	TV	TV	110AC	-32.7	+5.5	NONE	CLOCK	NONE	TV	ECS-1
18	"	"	"	"	"	"	"	"	"	"	"	"	TV	ECS-1
61	LAND	NONE	NONE	-	0-00	0-00	110AC	-60m		SELF	100 CPS	NONE	05	DECK BN-3
62	"	"	"	-	"	"	"	"	"	"	"	"	"	BM-6
63	"	"	"	-	"	"	"	"	"	"	250 CPS	"	"	BM-1
64	"	"	"	-	"	"	"	"	"	"	100 CPS	"	"	BM-8
39	TAI X	NONE	NONE		CLOCK	24 DC		BB	BB-	NONE	NONE	CLOCK	EGG-	
40	"	"	"		"	"		BB	BB-	"	"	"	"	EGG-
16,020	Plus X	0	0	8	VARIED		MANUAL WYCKOFF	0	+30m	-	-	-	05	SPD. DECK GR.
021	"	0	0	8	"		"	"	"				"	"
022	"	0	0	11	"		"	"	"				"	"

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

## CAMERA DATA SHEET

TEST INV-11 DATE 11/1/52 STA. CURTISS

CURTISS

EDGERTON, GERMESHAUSEN & GRIER, INC.  
CURTISS

## CAMERA DATA SHEET

TEST Ivy - MIKE DATE 11/1/52 STA. CURTISS

EDGERTON, GERMESHAUSEN & GRIER, INC.

CAMERA DATA SHEET  
TEST Ivy-M DATE 1/1/52 STA. A/C

## AIRCRAFT

EDGERTON, GERMESHAUSEN & GRIER, INC.

## CAMERA DATA SHEET

## AIRCRAFT

TEST Ivy-Mike DATE 11/1/52 STA. A/C

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

### CAMERA DATA SHEET

TEST Ivy-K DATE 11-16-52 STA. 301

PARRY TOWER

**SECRET - RESTRICTED DATA**

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

## **CAMERA DATA SHEET**

TEST Ivy-King DATE 11-16-52 STA. 301

PARRY TOWER

PERF.	EMULS	FILTERS		APER.	AIMING		POWER	TIMING		MARKERS, SERIALS			RACK	CAM	
		CODE	ND	Color	SET.	HORIZ.		ON	OFF	FM.	VEL.	ZERO	POS.		
16.241	HRHS	NONE	NONE	11	0-00	1-30	115AC	-1570	+458	8	NONE	NONE		B-30	
42	MF	"	"	"	"	"	24DC	-258	+58	21	"	"		4	
43	"	"	"	"	"	"	"	"	"	13	"	"		9	
44	"	"	"	"	"	"	"	"	"	21	"	"		15	
45	HRHS	"	"	"	"	"	"	"	"	3	"	"		19	
46	"	"	"	"	"	"	"	"	"	8	"	"		22	
47	"	"	"	"	"	"	"	"	"	13	"	"		2	
48	Tri X	"	"	"	"	"	"	"	"	21	"	"		33	
49	"	"	"	"	"	"	"	"	"	8	"	"		8	
50	"	"	"	"	"	"	"	"	"	21	"	"		10	
51	"	"	"	"	"	"	"	"	"	13	"	"		14	
52	"	"	"	"	"	"	"	"	"	3	"	"		24	
00	ECN	1	NONE	8	0-00	5-30	85AC	0/30	-2.58	SELE+5	8	200-109	109	—	F-6
98	ECN	0	0	26	0-00	1-30					3	100-108			GMX-9
99	S-XX	0	0	26	0-00	1-30	110AC				19	"			"
96	LIN 809				0-00	0-00	24 DC				"				GMX-1
28	S-XX	step	12	—	0-00	0-00	120AC	-2.58	SELE+58	8	200-109	109		GR-2	
29	ECN	"	NONE	—	"	"	"	"	"	8	-109	109		GR-3	
22	ECN	2	NONE	8 15°	0-00	2-30	120AC		+458	NONE	100-108	NONE		MH-11	
21	"	1	"	5.6 15°	"	14-00	"	"	"	"	"	"		MH-16	
95	ECN														
26	ECN	0	0	22-4	0-00	3-00	115AC	MANUAL		NONE	NONE	CL		BH-7	

## EDGERTON, GERMESHAUSEN & GRIER, INC.

**CAMERA DATA SHEET**

PARRY GND.

## EDGERTON, GERMESHAUSEN & GRIER, INC.

## **CAMERA DATA SHEET**

PARRY GND.

TEST Ivy-King DATE 11-16-52 S7A.302 & 308

## EDGERTON, GERMESHAUSEN & GRIER, INC.

## CAMERA DATA SHEET

TEST Ivy-K DATE 11-16-52 STA. 304

## CORAL

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

## CAMERA DATA SHEET

TEST Ivy-King DATE 11-16-52 STA. 304

## CORAL

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

## **CAMERA DATA SHEET**

TEST Ivy-K DATE 11-16-52 STA. 306a

Rojo

REMARKS & NOTES		CAMERA			TIME	LENS	
PURPOSE	~ FR./SEC.	NO.	SERIAL	MAG.	OPER.	FOC.	LGH.
2 ~ = 1.96 cps	VIEWST-MONTAESTA NO. 62110	75	MH-15	990	0-45 S	152	BF 2534
1.93 "	"	75	MH-14	991	"	"	BF 2530
1.94 "	12	75	MH-17	993	"	"	BF 2331
1.92 "	13	"	MH-2	747	"	"	BF 2599
1.96 "	14	"	MH-16	992	"	"	BR 6743
1.95 "	15	"	BH-1	1084	"	"	BF 2355
1.96 "	ROCKETS	"	MH-7	742	"	35	BF 5746
1.95 "	"	"	MH-13	989	"	50	LF 6969
1.96 "	"	"	MH-1	748	"	100	BF 9465
Survey		Single	TW148	148		166.15	148
"		"	TG058	052		168.40	115

## EDGERTON, GERMESHAUSEN & GRIER, INC.

## **CAMERA DATA SHEET**

TEST Ivy-King DATE 11-16-51 STA. 306

RojoA

PERF. CODE	EMULS.	FILTERS		APER. SET.	AIMING		POWER	TIMING		MARKERS, SERIALS			RACK POS.	CAM NO.		
		ND	COLOR		HORIZ.	VERT.		ON	OFF	FM.	VEL.	ZERO				
16,276	MF	1	12.	8	15°	12-00 R	0-00	120 DC	-15.3	+45 S	NONE	2-5	A2NE	D	MH-15	
77	"	1	"	"	"	14-32 R	"	"	"	"	"	"	2-16	"	C	MH-14
78	"	1	"	5.6	15°	17-18 R	"	"	"	"	"	"	2-11	"	B	MH-17
79	"	0	"	8	15°	20-12 R	"	"	"	"	"	"	2-17	"	H	MH-2
80	"	0	"	4	45°	29-18 R	"	"	"	"	"	"	2-13	"	G	MH-16
81	"	0	"	2.7	170°	44-39 R	"	"	"	"	"	"	2-4	"	F	DR-1
91	"	0	"	5.6	15°	0-00	4-08	"	"	"	"	"	2-1	"	E	MH-7
92	"	0	"	8	15°	2-50 L	"	"	"	"	"	"	2-8	"	I	MH-13
93	"	0	"	11	15°	0-00	"	"	"	"	"	"	2-12	"	A	MH-1
34	MF	2	12	32	1/800	0-00	0-00	24 DC	BB	BB	NONE	NONE				TW-16
53	"	2	12	16	1/500	"	"	12 DC	"	BB	"	"				TE-051

**EDGERTON, GERMESKAUSEN & GRIER, INC.**

CAMERA DATA SHEET  
TEST Ivy-K DATE 11-16-51 STA. 307

RUNIT

**EDGERTON, GERMESHAUSEN & GRIER, INC.**

## CAMERA DATA SHEET

TEST Ivy-King DATE 11/16-52 STA. 307

Runit